Flow Measurement

INTRODUCTION

Application areas:

- Transportation of solids as slurries
- CNG in pipelines
- Domestic water & gas supply
- Irrigation systems
- Industrial process control system

Types of Flows:

- Clean or dirty
- Wet or dry
- Hazardous/corrosive or safe
- Laminar or transitional or turbulent
- Vacuums to high pressures
- Various temperature ranges

Selection of instrument depends on

- Nature of the metered fluid and the demands of the associated plant.

  Eg. Aircraft fuel meter should be compact, not affected by changes in orientation and has to handle clean & non corrosive fluid. While some industrial flow meters should be large, fixed type and may have to handle corrosive fluids with foreign matters.
- Performance parameters like range, accuracy, repeatability, linearity, dynamic response, type of output, etc
- Recording or indicating type, measuring rate of flow or total flow, etc.

PRIMARY OR QUANTITY METERS

- Measures amount of fluid in terms of mass or volume that flows past a given point in a definite period of time.
- Average flow rate can be evaluated.
- Simple economical and accurate method.
- Used in the calibration of other flow measuring devices.
- Calibration procedure have two categories

1. Volumetric method: fluid in flow meter is collected into a tank of known volume. When the tank is filled , then this volume is compared with the integrated, volumetric quantity registered by flow meter under test.

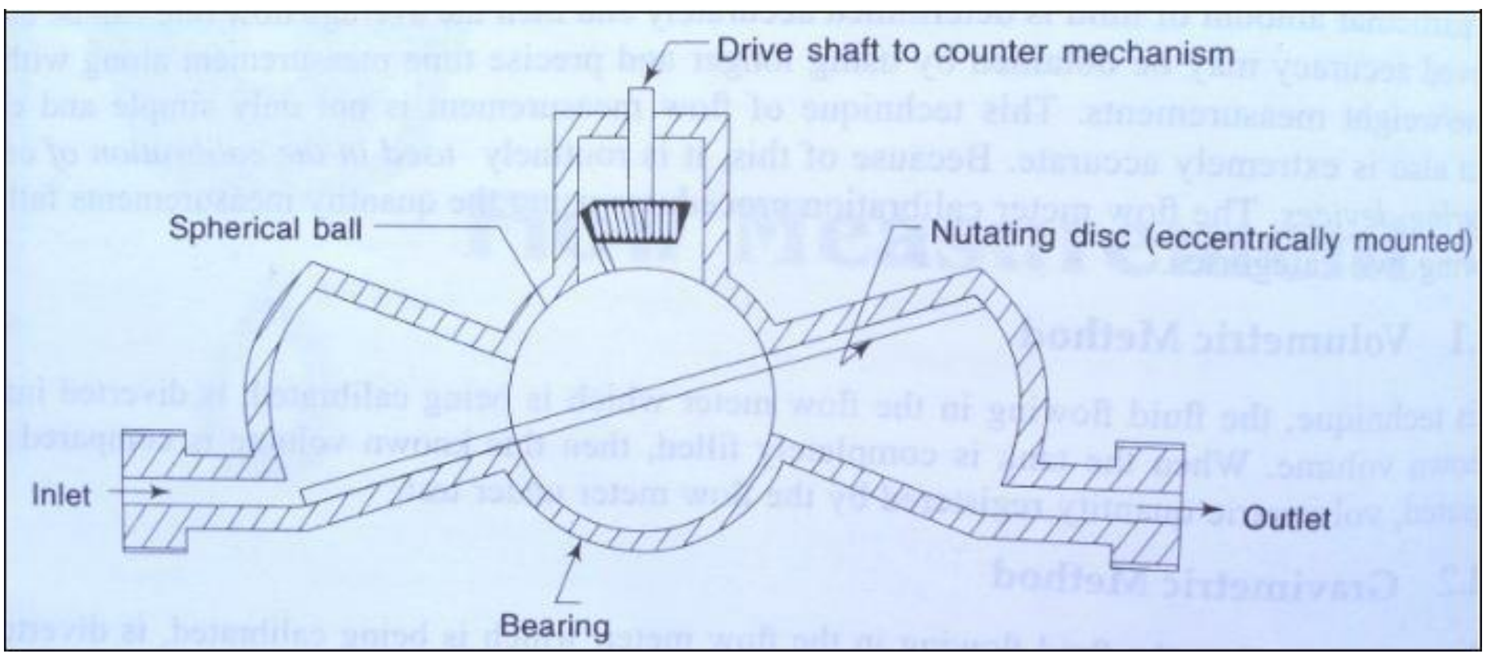
2. Gravimetric Method: the weight of the liquid collected as above is compared with the gravimetric quantity registered by the flow meter under test.

Positive Displacement Meters

- Principle: the liquid flows through a meter and moves the measuring element that seals the measuring chamber into a series of measuring compartments each holding a definite volume.
- Used in low flow rate metering applications where high accuracy & repeatability under steady flow conditions are required.
- Easy to install, maintain and have moderate costs.
- Used for mainly water & oil flow measuring.
- Contains moving parts, so wearing of it affect accuracy.
- Need frequent calibrations.
- Suitable only for clean fluids.
- Do not give instantaneous rate of flow.

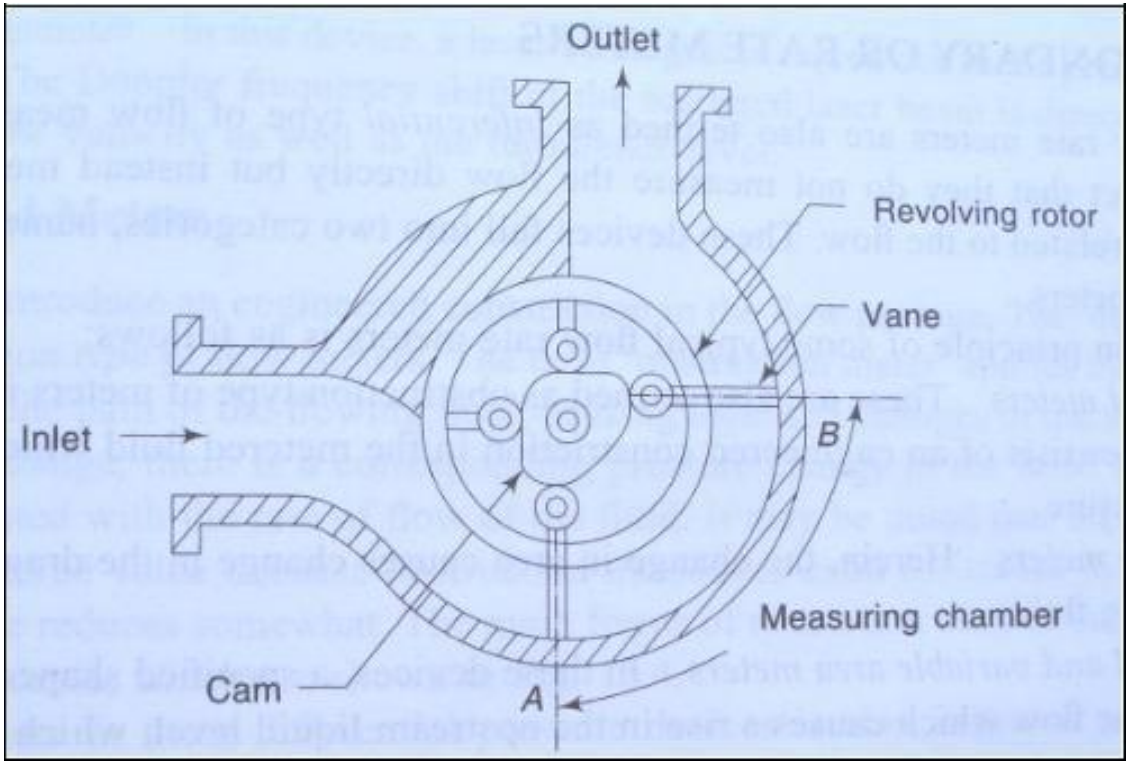
Nutating Disc Meter

- Consists eccentrically mounted disc which nutates / rock in the metering chamber which has spherical sides.
- Liquid from the inlet causes the disc to nutates before it goes to the outlet.
- Viscosity of liquid ensures both sealing & lubrication.
- Small spindle attached to sphere traces a circular path and is used to drive the mechanical or electronic counter calibrated with liquid discharge.
- Low pressure drop, good accuracy ($\pm$1%)
- Use – domestic water meter



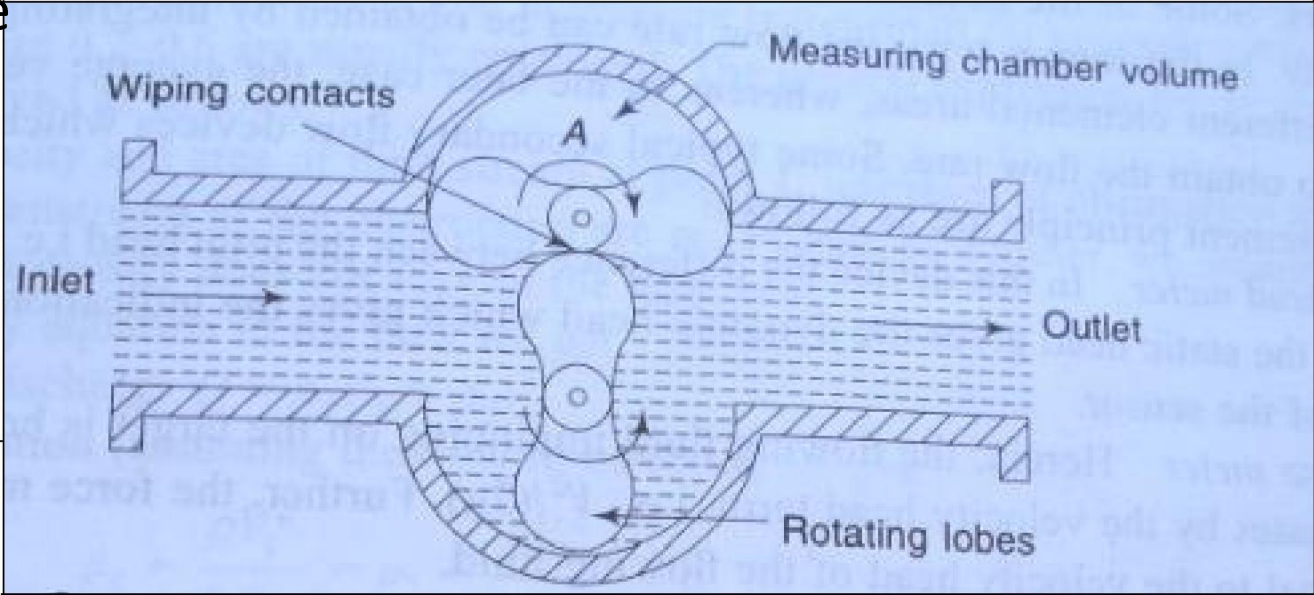
Sliding-Vane-Type Meter

- Accurately machined body having rotor with four evenly spaced slots which form guides for vanes.
- Liquid revolves the rotor & vanes around a cam causing the vanes to move radially.
- A continuous series of chambers at the rate of four per revolution are formed which deliver the flow at the outlet.
- Low pressure drop, accuracy ± 0.2%.
- Use – flow of petrol / diesel or CNG in the fuel filling stations.



Lobed-impeller Meter

- Consists two lobed rotors mounted on separate parallel shaft which revolve in opposite direction in a close fitting chamber.
- Rotor lobes have involute or cycloidal shape for accurate fitting.
- For every rotation swept volume (2A) is passed through meter. Thus number of revolutions of rotor gives an indication of volumetric flow.
- speed of rotation is proportional to the volume flow rate.
- Low pressure drop & accuracy $\underline{+}1\%$.
- Relatively expensive
- Use – metering of gas flows & refined petroleum products.



SECONDARY OR RATE METERS

- Termed as *Inferential* type of flow measuring devices.
- They do not measure flow directly, but measure another quantity which is related to flow.

1. Flow Rate Meters
- Variable head meters
- Variable area meters
- Variable head and variable area meters
- Constant head device

2. Velocity Meters
- Variable head meters
- Target flow meter
- Turbine / propeller type meter
- Ultrasonic flow meter
- Electromagnetic flow meter
- Hot wire / hot film anemometer
- Laser Doppler anemometer

Variable head meters

- Generally termed as obstruction type flow meter.
- The variation in pressure change (due to variation in velocity) is correlated with rate of flow of fluid.
- Causes loading error due to resistance by obstruction.
- Restriction used are venturi tubes, orifice plate and nozzle.
- The position of minimum pressure is located slightly downstream from restriction at a point where the stream is the narrowest and is called the ‘*vena-contracta*’.
- The ratio of diameter at the constriction ‘d’ to the diameter D of the pipe is called the diameter ratio.
- If the ratio is too small, pressure loss becomes considerable and efficiency of measurement is low.
- In practice, ratio is in the range of 0.2 to 0.6

… expression for the rate of flow in … as follows:

Say, the pressure, velocity and area of fluid stream at point 1, upstream of obstruction are p_1, V_1 and A_1 and at point 2 just downstream of the obstruction are p_2, V_2 and A_2. Further, we assume the flow to be incompressible, i.e., its density does not vary in the flow field.

Applying the continuity equation in the flow we get

$$\text{Rate of discharge } Q = A_1V_1 = A_2V_2 \tag{13.1}$$

Applying Bernoulli's equation (assuming the flow to be ideal) we get,

$$p_1 + \frac{\rho V_1^2}{2} = p_2 + \frac{\rho V_2^2}{2} \tag{13.2}$$

The differential pressure head Δh is given by

$$\frac{p_1 - p_2}{\rho g} = \Delta h \tag{13.3}$$

Eliminating V_1 and V_2 from Eqs. (13.1) and (13.2) and substituting the value of Δh from Eq. (13.3) we get the ideal rate of discharge as

$$Q_{\text{ideal}} = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \cdot \sqrt{2g}\,\sqrt{\Delta h} \tag{13.4}$$

In actual practice, the actual rate of fluid flow is always less than Q_{ideal} as given by Eq. (13.4), because of the losses in the fluid flow due to friction and eddying motions. To account for this discrepancy, we define the term coefficient of discharge C_d as

$$C_d = \frac{Q_{\text{actual}}}{Q_{\text{ideal}}} \tag{13.5}$$

Thus, we can write the actual rate of fluid flow as

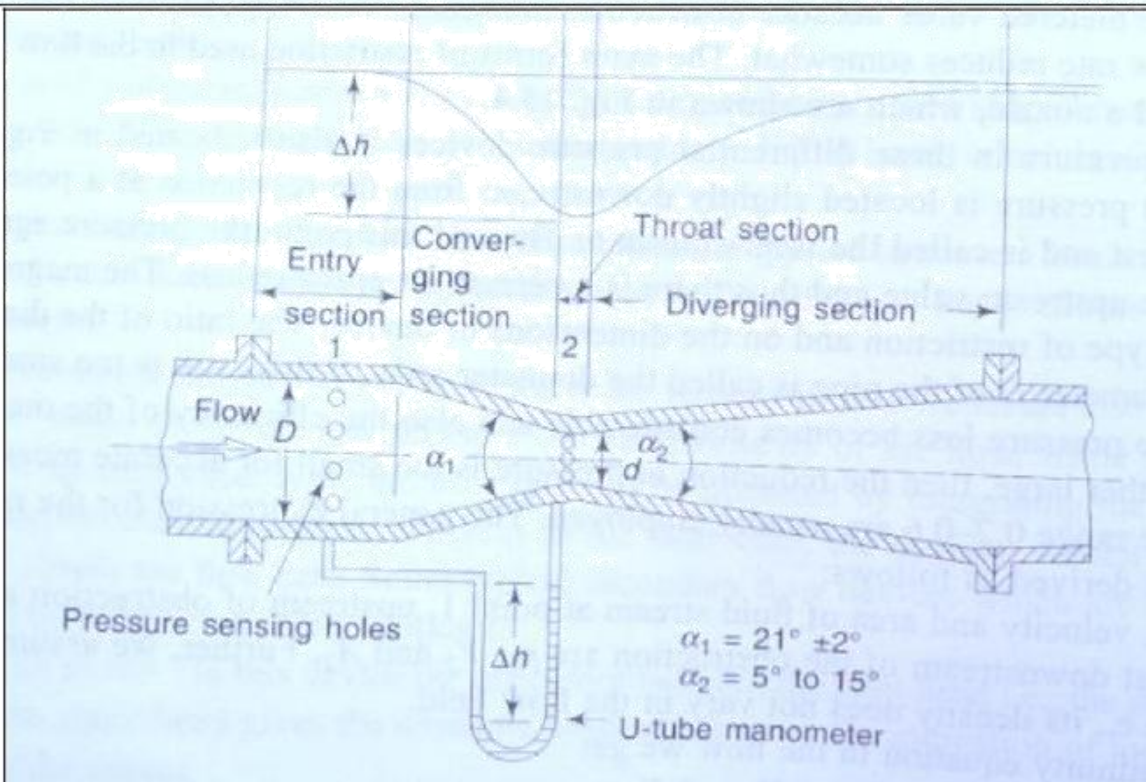
$$Q_{\text{actual}} = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2g}\,\sqrt{\Delta h}$$

Equation (13.6) can be rewritten in the simplified form as

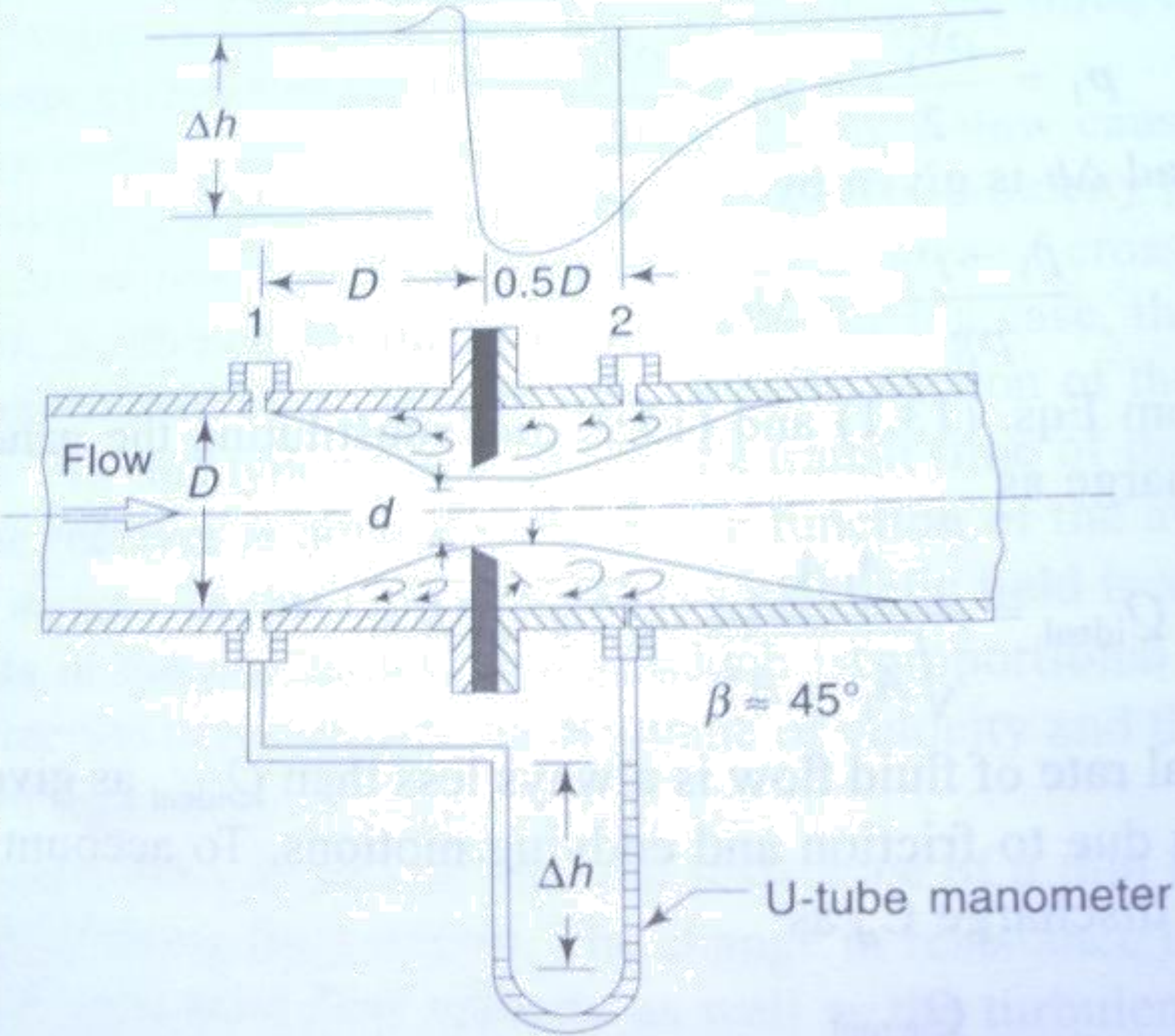
$$Q_{\text{actual}} = C_d K\,(\Delta h)^{1/2}$$

where K is the constant of flow obstruction device and

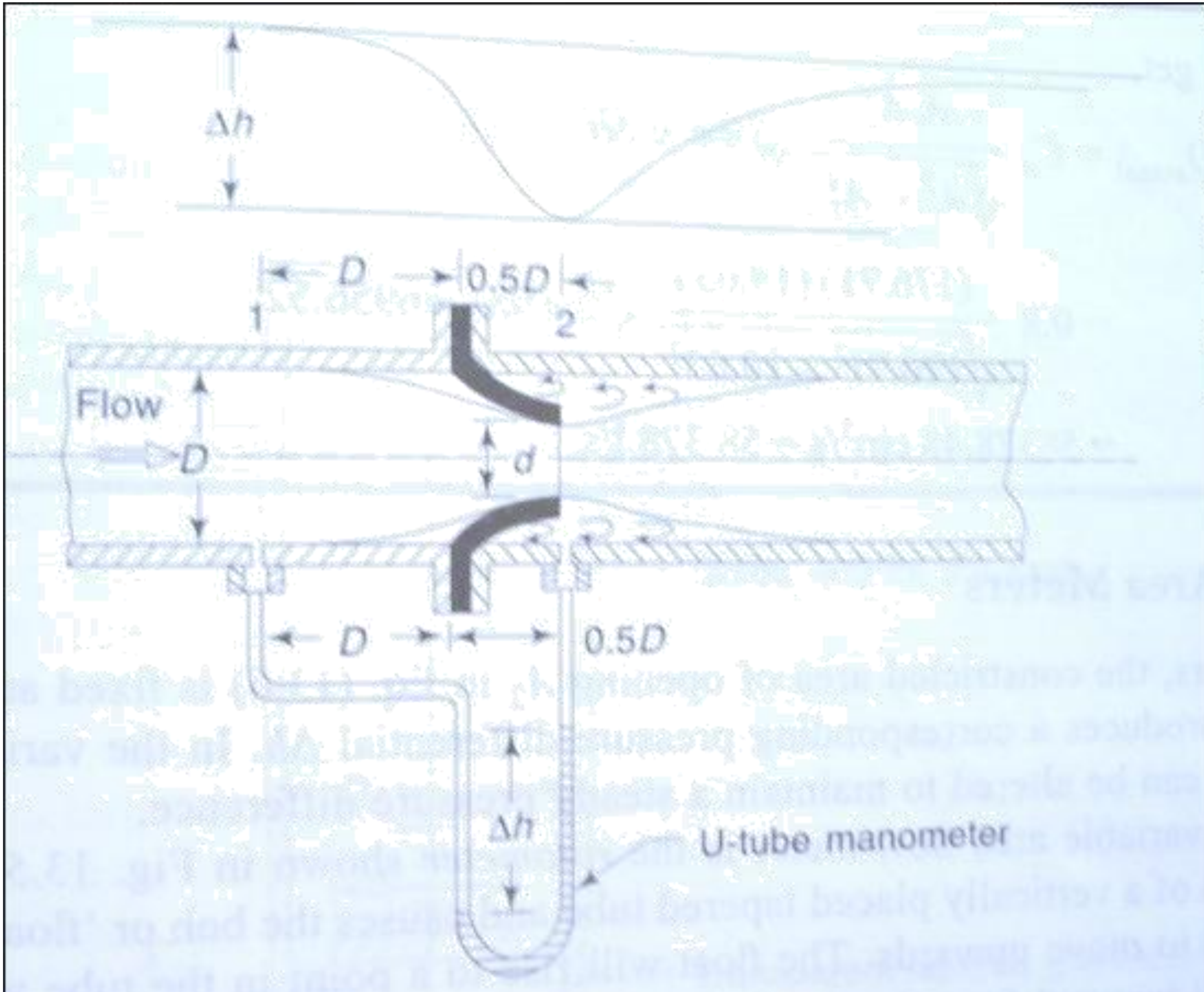
$$K = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2g}$$



(a) Venturi meter



(b) Orifice meter



(c) Nozzle meter

- **Venturimeter** offers the best accuracy, least head loss.
- Due to low losses, coefficient of discharge is high approaching to unity.
- Expensive and occupies more space.
- **Nozzle flow meter** offers all advantages of venturimeter but in lesser extent.
- Occupies less space.
- Difficult to install.
- **Orifice meter** consists of thin orifice plate clamped between pipe flanges.
- Geometry is simple, low cost, easy to install or replace and takes no space.
- Suffers head loss upto 30-40%.
- Variable head devices have no moving parts and require no maintenance.

Variable Area Meters

- The constricted area of opening A_2 is fixed and the change in the volume rate of flow produces a corresponding pressure differential Δh. the area of the restriction can be altered to a maintain a steady pressure difference.
- The commonly used variable area flow meter is the rotameter.
- Flow enters the bottom of a vertically placed tapered tube and causes the bob or float to move upwards.
- The float will rise to a point in the tube where drag force and buoyant force is balanced by the weight of float.
- The position of the float in the tube is taken as an indication of the flow rate.
- Also called variable area orifice meter.

The force balance equation of the float is

$$F_{\text{drag}} + F_{\text{buoyancy}} = F_{\text{weight}}$$

$$A_f(p_d - p_u) + \rho_{ff}\, g\, V_f = \rho_f\, g\, V_f \tag{13.8}$$

$$(p_d - p_u) = \frac{V_f}{A_f}\, g(\rho_f - \rho_{ff}) \tag{13.9}$$

where ρ_f and ρ_{ff} are the densities of the float and flowing fluid, respectively

V_f is the volume of the float

p_d and p_u are the pressures at the downward and upward faces of the float, respectively.

Now a kind of constriction is formed between the downward surface and upward surface of the float. Using Eq. (13.6) we get the volume rate of flow:

$$Q_{\text{actual}} = C_d \frac{A_t(A_t - A_f)}{\sqrt{A_t^2 - (A_t - A_f)^2}} \sqrt{2g} \sqrt{\frac{(p_d - p_u)}{\rho_{ff}\, g}} \tag{13.10}$$

where A_t is the area of the tube at the float level $(A_t - A_f)$ is the minimum annular area between the tube and the float and C_d is the coefficient of the discharge.

Substituting the value of $(p_d - p_u)$ from Eq. (13.9) we get,

$$Q_{\text{actual}} = \frac{C_d(A_t - A_f)}{\sqrt{1 - (A_t - A_f)^2 / A_t^2}} \sqrt{2g} \sqrt{\frac{V_f}{A_f} \cdot \frac{(\rho_f - \rho_{ff})}{\rho_{ff}}} \tag{13.11}$$

If the variation of C_d with the float position is slight and if $(A_t - A_f)/A_t \ll 1$ then,

$$Q_{\text{actual}} = K(A_t - A_f) \tag{13.12}$$

where K is the constant of the rotameter.

If the angle of taper is θ (which is very small), then,

$$A_t = \frac{\pi}{4} (D_i + y \tan \theta)^2$$

$$= \frac{\pi}{4} D_i^2 + \frac{\pi}{2} y D_i \tan \theta$$

where y is the float position with respect to inlet, and

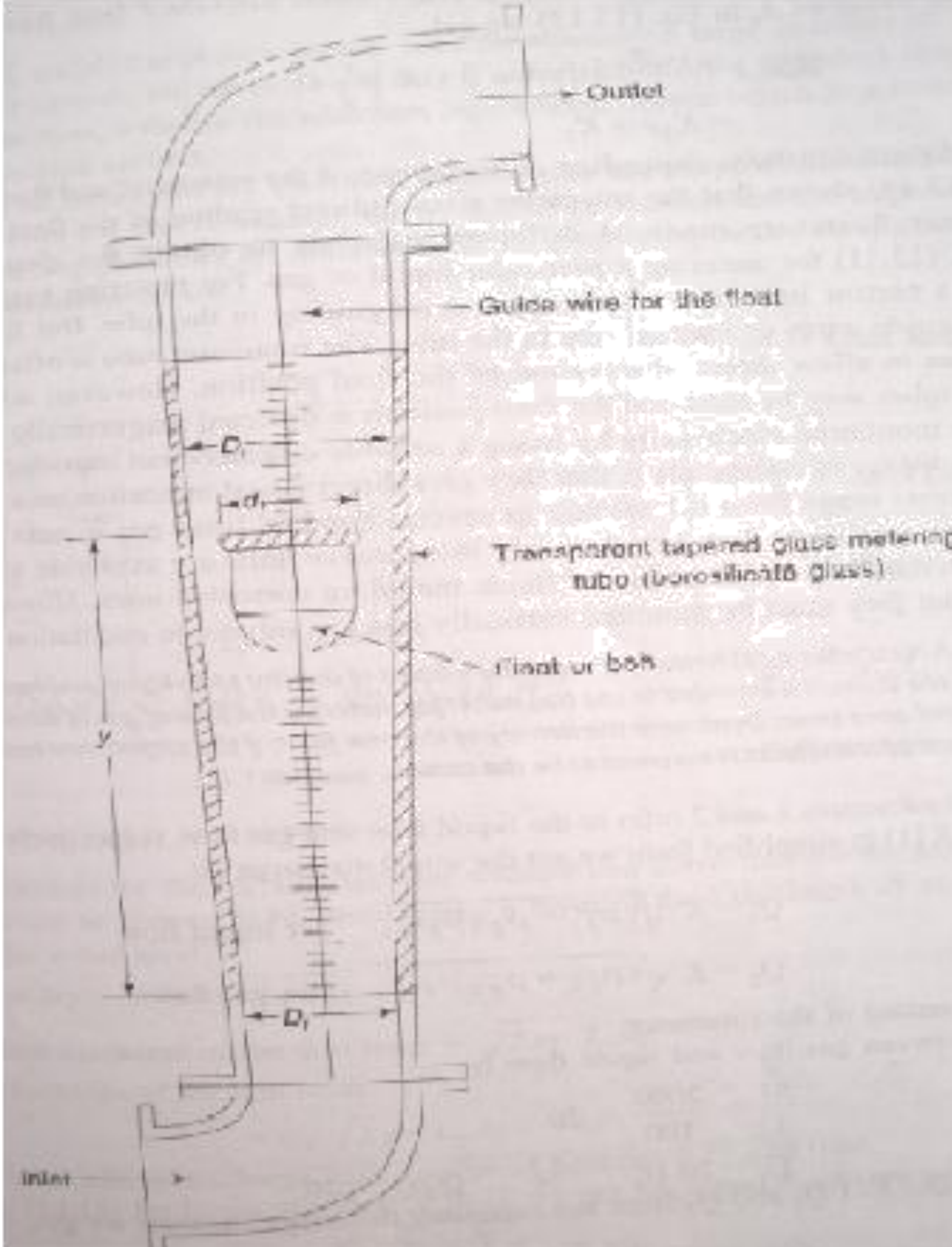
D_i is the diameter at the inlet.

Substituting the value of A_t in Eq. (13.12) we get,

$$Q_{\text{actual}} = K \frac{\pi}{4} D_i y \tan \theta + K \left(\frac{\pi}{4} D_i^2 - A_f \right)$$

$$= K_1 y + K_2$$

where K_1 and K_2 are constants depending on the shape of the rotameter and float.



Outlet
Guide wire for the float
D
d
Transparent tapered glass metering tube (borosilicate glass)
Float or bob
y
D
Inlet

- Rotameter gives a direct reading of float on a linear scale.
- For metering gases or air, a small sphere can be used in a narrow bore tube which require no guiding in the tube.
- For liquids, floats are kept central by gude wires or internal ribs in the tube.
- The rotameter tube is made up of high strength borosilicate glass to allow direct observation of float position.
- For greater strength metal tubes may be used & float position is detected magnetically.
- Capacity range from 0.1 ml/min to several hundred liters per minute.
- Accuracy ± 1% of max. flow rate.
- Can be used for corrosive fluids.
- Rotameters must be mounted vertically and are subject to oscillations in pulsating flows.