11 Flow Measurements

11.1 INTRODUCTION

The performance of engineering equipments and systems should be validated by tests and experiments before these could be commissioned. Tests and experiments involve various measuring instruments. Performance tsting of pumps, teurbines, fans and blowers are typical cases.

Other areas requiring measurement of flow parameters are irrigation systems, chemical process control and research work in fluid mechanics.

Out of the many parameters to be measured, flow velocity and flow rate are involved in almost all cases. Measurement of pressure and pressure difference between locations are discussed in chapter 2.

In this chapter the methods and instruments for the measurement of flow velocity and flow rate are described.

11.2 VELOCITY MEASUREMENTS

The measurement of velocity at a point or a number of points throughout a section in a flow stream is often needed to establish the velocity profile. Measurement of velocity at a point is almost impossible, since any sensing device has a finite dimension. However, if the area of flow occupied by the sensing device is relatively small compared to the total area of flow stream, then it may be considered that the velocity measured is the velocity at a point. It is essential that the presence of the sensing device in the flow stream does not afffect the flow being measured. **Velocity is usually measured indirectly by measuring the difference between the stagnation and static pressures** (pitot tube) or by the rotational speed of wheels (vane anemometer) or by the temperature drop on a thin cylindrical wire in cross flow (hot wire anemometer) and also by optical systems. Velocity is also measured directly, in some instances, by determining the distance travelled by a group of fluid particles during a measured time interval.

11.2.1 Pitot Tube

If a small bore hollow tube bent at 90° is placed in a flow stream with its end facing upstream, fluid will rise in the vertical side of the tube as shown in Fig 11.2.1 (*a*). This method is used as pick-up in velocity measurment.

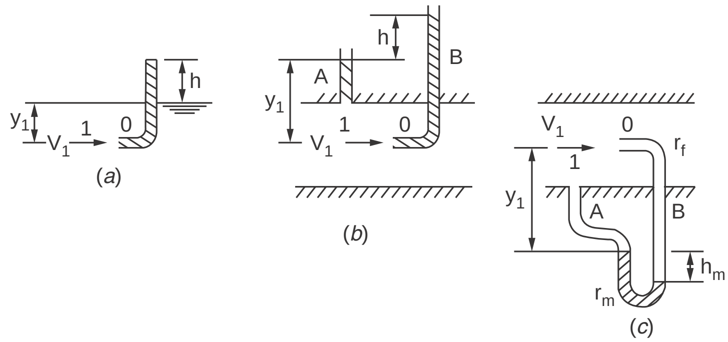

Figure 11.2.1 Pitot tube arrangements

If Bernoulli equation is applied between a point, 1 upstream at the submerged end of the tube and a point, 0 at the other end of the tube, then leaving out P_{atm} on both sides

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_0}{\rho g} \tag{11.2.1}$$

Since stagnation condition exists within the tube

$P_0 = \rho g(y + h)$, at point 1, the static pressure is $P_1 = \rho g y_1$

Substituting and rearranging equation (11.1)

$$\frac{V_1^2}{2g} = \frac{(P_0 - P_1)}{\rho g} = \frac{\rho g[(y_1 + h) - y_1]}{\rho g} = h\ ,$$

$$\therefore \qquad V_1 = \sqrt{2gh} \tag{11.2.2}$$

Note that **h is the head expressed as the column of flowing fluid.**

For velocity measurement in ducts a different arrangement of pick ups is necessary. A typical method is illustrated in Fig. 11.2.1 (*b*). A tapping perpendicular to the flow gives the static pressure. The tube connection at this point is called static tube/probe. The pitot probe held facing upstream measures the total pressure.

The static tube *A* and pitot tube *B* are connected to a *U* tube manometer as shown in Fig. 11.2.1 (*c*) for measurement of velocity in a pipe. Equating the pressure at the left and right side limbs of the manometer,

$$P_1 + \rho g y_1 + \rho_m g\, h_m = P_0 + \rho g y_1$$

$$h_m g(\rho_m - \rho) = P_0 - P_1 \tag{11.2.3}$$

where ρ and ρ_m are the densities of flowing and manometric fluids. Substituting for $(P_0 - P_1)$ from equation 11.2.1,

$$h_m g\,(\rho_m - \rho) = \frac{\rho V_1^2}{2}$$

∴ The velocity of fluid near the tip of the pitot at section 1 is

$$V_1 = \sqrt{2gh_m(\rho_m - \rho)/\rho} = \sqrt{2gh_m((\rho_m/\rho) - 1)} \tag{11.2.4}$$

ρ_m/ρ is to be replaced by s_m/s in terms of specific gravities.

Though the set up illustrates the basic principle involved in the measurement, it is not a practical arrangement. In practice the two tubes are combined together to be used as a single instrument called pitot static tube as shown in Fig. 11.2.2 (*a*) and (*b*). This set up (Fig. 11.2.2(*a*)) is due to Prandtl and it is more accurate over the design of Brabbee as shown in Fig. 11.2.2 (*b*).

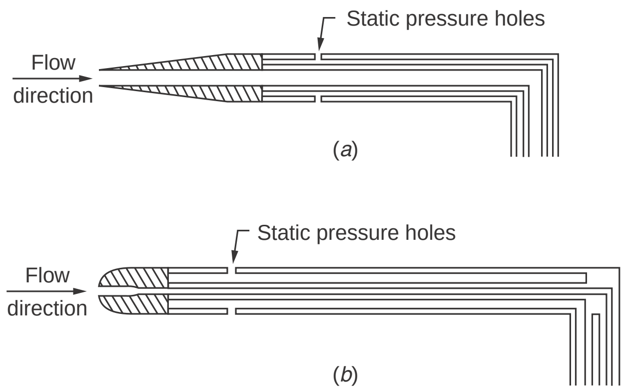

Figure 11.2.2 Prandtl and Brabbee pitot tubes

In both these cases, the inner tube measures the stagnation pessure and the tube with opening on the surface measures the static pressure. The accuracy of the measurement is found to depend on the shape of the tip of the pitot tube. Turbulent flows with more fluctuations at the tip may show a higher reading compared to the time averaged velocity at that location. Hence equation 11.2.4 is modified as

$$V_1 = C_v\,\sqrt{2gh_m((\rho_m/\rho) - 1)} \tag{11.2.5}$$

where C_v is a coefficient and its value has to be determined by calibrating the device.

In the case of subsonic gas flow, the equation for the velocity should be modified, considering compressibility as

$$V_1 = C_v\,\sqrt{\frac{2kRT_1}{k-1}\left[\left(\frac{P_0}{P_1}\right) - 1\right]} \tag{11.2.6}$$

where $k = C_P/C_v$ the ratio of specific heats.

This instrument is extensively used for velocity measurements in gas flow.

Standards are available for these instruments, indicating the details of construction.

11.2.2 Vane Anemometer and Currentmeter

Vane anemometers and current meters are used to measure the velocity of air and water in larger flow fields. Hemispherical vanes are fitted on the radial arms of vane anemometer as shown in Fig. 11.2.3 (*b*) and cones are fitted on the current meter as shown in the Fig 11.2.3(*a*). Drag force on the vanes and cones when fluid moves over them causes the rotary movement of the rotor. Impeller type wheels are also used for the measurement of gas flow velocity. The speed of rotation is generally indicated by means of electrical contacts made once in each revolution and the number of contacts made per unit time interval is a direct measure of the average speed of the fluid in the region traversed by the meters. Calibration is done by towing the meters through stagnant water or air at known speeds. Atmospheric wind speed measurement is generally done using such devices.

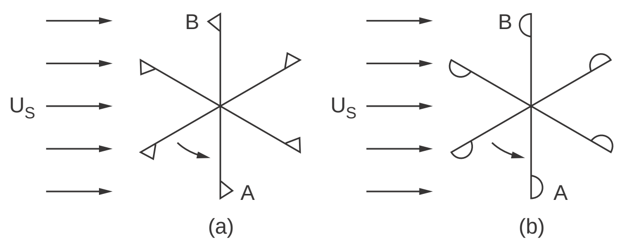

Figure 11.2.3 Vane anemometer

11.2.3 Hot Wire Anemometer

In hot-wire anemometers, an electrically heated thin wire is placed across a flowing stream. The heat transfer depends on the flow velocity. Two methods of measuring flow rate are:

1. Constant resistance method. The wire resistance is kept constant by adjusting the current flow through it and the velocity is determined by measuring the current and calibrating the instrument accordingly.

2. Constant current method. The current flow though the wire is kept constant and the change in wire resistance from convection cooling is measured in terms of the voltage drop across it. Fluctuations in velocity may be detected and recorded by suitable circuitry.

When the hot wire is placed in a flowing stream, heat will be transferred from the wire mainly by convection, radiation and conduction being negligible. The following relationship is used to determine the velocity.

$$\frac{\text{Power/unit length}}{\text{Temperature difference}} = \frac{I^2 R}{T_w - T_a} = A + B\sqrt{\rho V}$$

where I is the instantaneous current, R is the resistance of wire per unit length, T_w is the temperature of the wire, T_a is the ambient temperature, V is the free stream velocity and ρ is the density of the fluid with constants A and B to be determined by calibration. The pick ups are shown in Fig. 11.2.4.

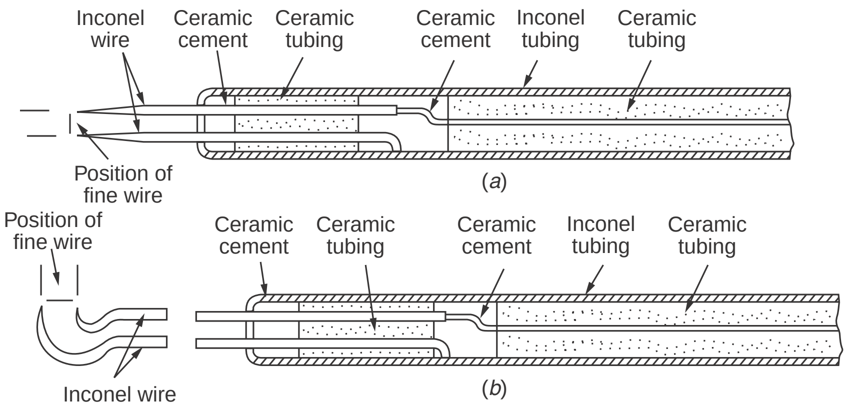

Figure 11.2.4 Hot wire anemometer

11.2.4 Laser Doppler Anemometer

Laser Doppler anemometer is used to measure the velocity of a flow without disturbing the flow. It is often used to measure turbulent velocity and also low volume flow rates. It measures the velocity of small particles that are either naturally present in most liquid flows or are seeded with 1 μm size particles in gas flows. This size of particle can generally follow all motions in the fluid in which it is carried. The reference beam mode with frequency tracking shown in Fig. 11.2.5 is one of the technique used for velocity measurement.

The light scattered off a moving particle has its frequency shifted by an amount that is proportional to the particle speed. A laser of fixed wavelength serves as a source of light and optical components split the laser beam into a reference beam and a secondary beam which are made to intersect at the measurement volume in the flow field. Frequency shifted light that is scattered off particles passing through the measurement volume and the unshifted beam is collected at a photodetector. There is an amplitude variation due to the frequency modification between the two beams. A frequency tracking filter locks onto the modulation frequency in the photodetector output to obtain the Doppler frequency which is linearly related to the velocity component through the optical system geometry. The doppler frequency will vary with time in unsteady laminar or turbulent flow. A continuous velocity signal is possible with this type of measurement system from which turbulence characteristics can be analysed.

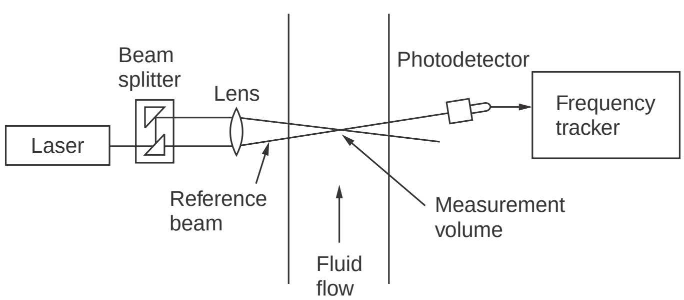

Figure 11.2.5 Laser Doppler anemometer

Multicomponent measuring systems can be developed by using laser with different wave lengths or other frequency shifting techniques. The major disadvantage of this system is its high cost and the requirement of optical access to the flow field.

11.3 VOLUME FLOW RATE MEASUREMENT

Volume flow rate in pipes can be measured either using direct measuring devices such as watermeter or rotameters (float meters) or using a constriction or elbow meters which produce a measurable pressure difference that can be used to determine the flow rate.

Flow meters (watermeter or rotameter) may be calibrated either by the manufacturer or by the user before installation. The same fluid and same range of flows as in the actual installation should be used for the calibration.

In the case of constriction meters Bernoulli equation and continuity equation are applied between the upstream and downstream sections of the constriction to obtain an expression for the flow rate.

11.3.1 Rotameter (Float Meter)

The rotameter is a device whose indication is essentially linear with flow rate. This device is also called as variable area meter or float meter. In this device a flot moves freely inside a tapered tube as shown in Fig. 11.3.1

The flow takes place upward through the tube. The following forces act on the float (*i*) downward gravity force (*ii*) upward buoyant force (*iii*) pressure and (*iv*) viscous drag force.

For a given flow rate, the float assumes a position inside the tube where the forces acting on it are in equilibrium. Through careful design, the effects of changes in viscosity or density may be minimized, leaving only the pressure forces as the main variable. Pressure force depends on flow rate and area available for flow. Hence the position of the float indicates the flow rate.

A major limitation in using rotameters is that these have to be installed in vertical position only. Also it cannot be used with liquids containing large number of solid particles and at high pressure conditions. It is also expensive. The advantage is that its capacity to measure the flow rate can be easily changed by changing the float or the tube.

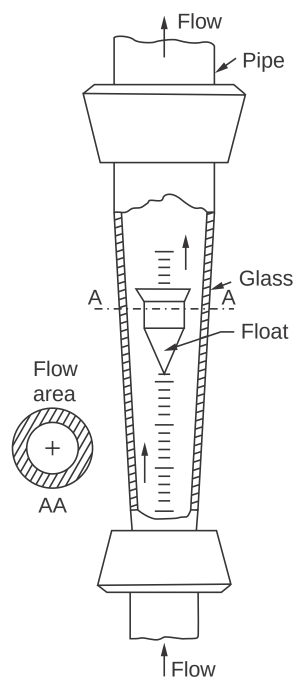

Figure 11.3.1 Rotameter

11.3.2 Turbine Type Flowmeter

Turbine type flow meter is used to measure flow in closed conduits. Propeller rotors are used in this meter. The number of turns of the rotor per unit time is counted and used as a measure of the flow rate. The rotor movement is sensed by a reluctance pickup coil. A permanent magnet in the rotor body produces a voltage pulse everytime the rotor blade passes the pole of the coil. The pulse rate may be indicated by a frequency meter or displayed on a *CRO* screen or counted by some type of meter which converts the pulses to a proportional *DC* output. The major problem inherent in this type of meter is the reduced accuracy at low flow rates. As there is no intrusion in to the flow this type can be used to measure flow of chemicals also. The arrangement is shown in Fig. 11.3.2.

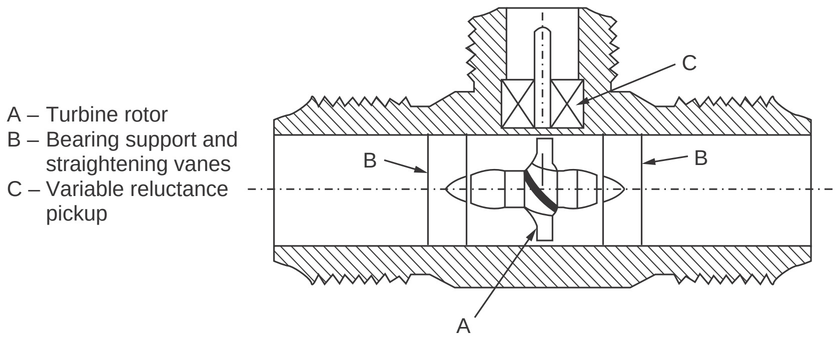

Figure 11.3.2 Turbine flowmeter

11.3.3 Venturi, Nozzle and Orifice Meters

Venturi, Nozzle and Orifice meters are the three obstruction type meters commonly used for the measurement of flow through pipes. In each case the meter acts as an obstacle placed in the path of the flowing fluid causing local changes in pressure and velocity as shown in Fig. 11.3.3.

Applying Bernoulli and continuity equations between sections 11.1 and 11.2

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 \text{ and } V_1 A_1 = V_2 A_2$$

Solving these equations,

$$V_2 = \frac{1}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2g[(p_1/\rho g + Z_1) - (P_2/\rho g + Z_2)]}$$

By connecting a manometer to the tappings at sections 11.1 and 11.2 the difference in pressure levels $\left[\left(\frac{P_1}{\rho g} + Z_1\right) - \left(\frac{P_2}{\rho g} + Z_2\right)\right]$ can be measured by the manometer reading, Δh.

$$\therefore \quad V_2 = \frac{1}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2g\Delta h}$$

$$\therefore \quad \text{Flow rate} \quad Q = \frac{A_2}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2g\Delta h}$$

Refer equations 11.2.3 and 11.2.2.

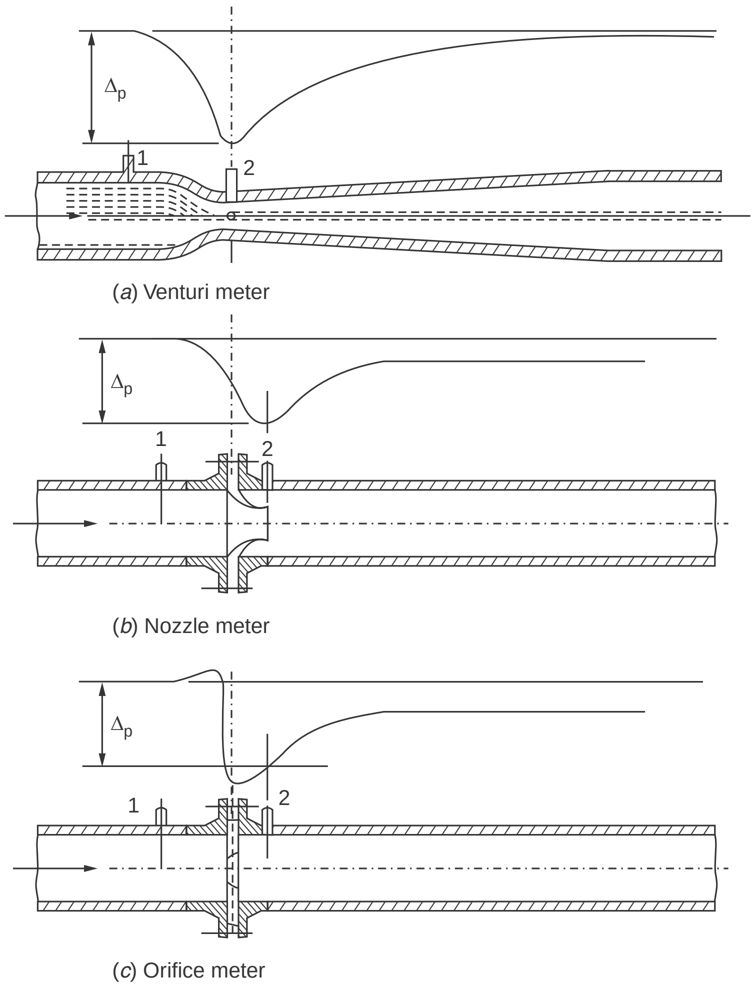

Figure 11.3.3 Pressure variation in obstruction type meters

This equation needs a modifying coefficient as viscous effects and boundary roughness as well as the velocity of approach factor that depend on the diameter ratio have been neglected. The coefficient is defined by,

$$\therefore \qquad Q_{\text{actual}} = Q_{\text{theoretical}} \times C_d$$

where C_d is the coefficient of discharge. Venturimeter is a highly accurate device with discharge coefficient falling within a narrow range depending on the finish of the entrance cone. C_d for venturi meters is in the range 0.95 to 0.98.

The approach curve in the nozzle flow meter must be proportioned to prevent separation between the flow and the well. A parallel section is used to ensure that flow fills the throat. C_d for flow nozzle is in the range 0.7 to 0.9 depending on diameter ratio and Reynolds number to some extent.

Orificemeter is the simple and cheap device compared to the other two. But sudden area of contraction in this device leads to higher pressure loss. The range for coefficient of discharge is 0.6 to 0.65. The value depends on the diameter ratio. Higher the value D_2/D_1 lower the value of the coefficient. In both the above cases for $Re > 10^5$ the effect of Re on C_d is marginal.

11.3.4 Elbow Meter

Elbow meter is used to measure the flow through a pipe. When the fluid flows through the elbow fitted in a pipe line, higher pressure results at the outer wall surface than at the innerwall surface. The difference in pressure at the outer and inner wall is a function of the flow rate. The pressure difference is measured using a manometer as shown in Fig. 11.3.4. The elbow meter is inexpensive and accurate if it is calibrated carefully.

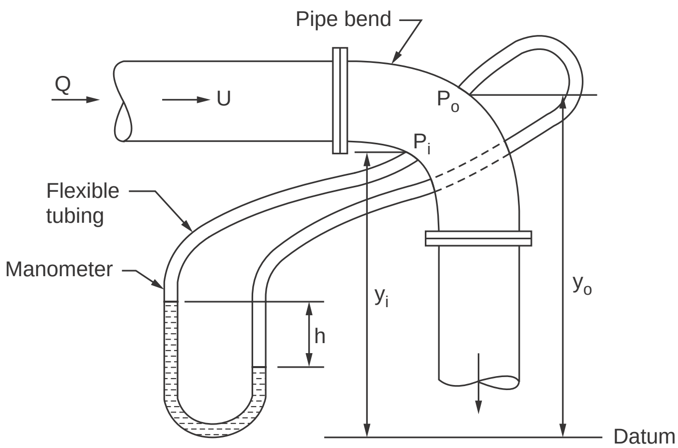

Figure 11.3.4 Elbow meter

11.4 FLOW MEASUREMENT USING ORIFICES, NOTCHES AND WEIRS

Flow out of open tanks are measured using orifices. Flow out of open channels is measured using weirs. Flow from open channels and tanks is due to gravity and the change in velocity produced is due to the change in head.

11.4.1 Discharge Measurement Using Orifices

Fig. 11.4.1 shows an orifice in an open tank through which the flow takes place. Applying Bernoulli equation between points 1 and 2

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

The velocity a point 1 is zero and the pressures at 1 and 2 are both atmospheric.

$$\therefore \qquad Z_1 - Z_2 = V_2^2/2g$$

$$V_2 = \sqrt{2g(Z_1 - Z_2)} = \sqrt{2gh}$$

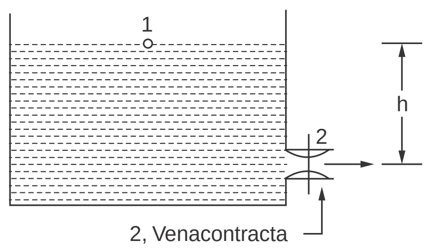

Figure 11.4.1 Orifice meter

The theoretical flow rate is given by $Q_t = A_2 \sqrt{2gh}$

where A_2 is the area of cross-section at section 11.2. The actual flow rate is given by

$$Q_{\text{actual}} = C_d A_0 \sqrt{2gh}$$

where A_0 is the area of orifice and C_d is the coefficient of discharge.

$$C_d = Q_{\text{actual}}/Q_{\text{theoretical}}$$

The values of C_d depends upon the contraction of the jet fromt the orifice to section 2 and on nonideal flow effects such as head losses which depend upon the roughness of the inside surface of the tank near the orifice and the flow rate. Typical value for C_d is 0.62.

Cofficient of velocity (C_v). There is alsways some loss of energy due to viscous effects in real fluid flows. Due to these effects, the actual flow velocity through the orifice will always be less than the theoretical possible velocity. The velocity coefficients C_v is defined as follows.

$$C_v = \frac{\text{Actual velocity of jet at venacontracta}}{\text{Theoritical velocity}} = \frac{V}{\sqrt{2gh}}$$

The value of C_v varies from 0.95 to 0.99 for different orifices depending on their shape and size.

Coefficient of contraction C_c. As water leaves an open tank through an orifice, the stream lines converge and the area just outside the orifice is lower compared to the area of the orifice. This section is called as vena contracta. Area of jet at the vena contracta is less than the area of the orifice itself due to convergence of stream lines. The coefficient of contraction C_c is defined as follows

$$C_c = \frac{\text{Area of the jet at vena contracta}}{\text{Area of orifice}} = \frac{a_c}{a}$$

The value of coefficient of contraction varies from 0.61 to 0.69 depending on the shape and size of the orifice.

Coefficient of discharge (C_d) Coefficient of discharge is defined as

$$C_d = \frac{\text{Actual discharge}}{\text{Theoretical discharge}} = \frac{\text{Actual area}}{\text{Theoretical area}} \times \frac{\text{Actual velocity}}{\text{Theoretical velocity}} = C_c \times C_v$$

Average value of C_d for orifices is 0.62.

11.4.2 Flow Measurements in Open Channels

Rectangular and triangular weirs are used to measure the flow in an open channel. A rectangular notch is shown in Fig. 11.4.2. A weir extends to the full width of the channel while a notch occupies a smaller width.

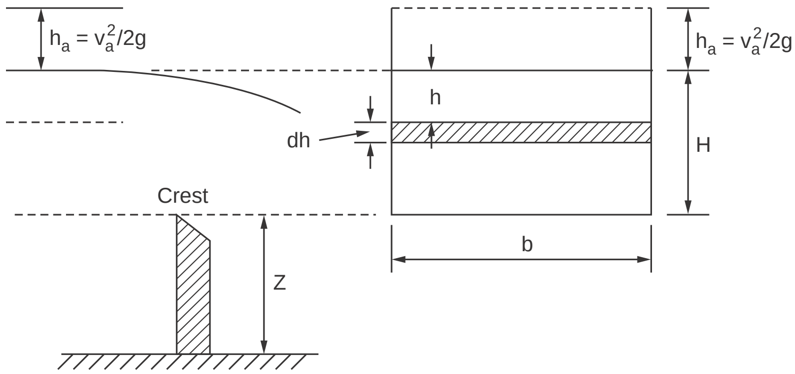

Figure 11.4.2 Rectangular weir

Rectangular weir. Bernoulli equation is applied between upstream and drown stream of the weir. Consider a rectangular strip as shown in figure, with height dh and width B at a height h above the strip.

Flow rate through the elemental strip = $dq = C_d\,(B\,dh)\,\sqrt{2gh}$

Integrating between the weir tip and the water level

Total discharge $$Q = \int_0^H C_d\,Bdh\,\sqrt{2gh} = C_d\,B\,\sqrt{2g}\,\int_0^H h^{1/2}\,dh$$

$$Q = C_d B\sqrt{2g}\left[\frac{h^{3/2}}{3/2}\right]_0^H \quad Q = \frac{2}{3}C_d B\sqrt{2g}\,H^{3/2} \tag{11.4.1}$$

The value of C_d depends the approach velocity which in turn depends on the ratio of head H and crest height z. The value of C_d is given by

$$C_d = 0.611 + 0.075\frac{H}{z} \tag{11.4.2}$$

A trapezoidal weir with side slope of 1 horizontal to 4 vertical is used to compensate for flow reduction due to end contraction at the corners. It is called **Cipolletti weir.** The flow equation is the same with B as bottom width. The value of C_d will however be different.

Discharge over a triangular notch. A triangular notch is called *V* notch as shown in Fig. 11.4.3.

Consider an elemental strip *dh,* the discharge through the elemental strip *dh* is

$$dq = C_d\left(2\,(H-h)\tan\frac{\theta}{2}dh\right)\sqrt{2gh}$$

Total discharge $$Q = \int_0^H C_d\left(2(H-h)\tan\frac{\theta}{2}dh\right)\sqrt{2gh}$$

$$= 2\,C_d\,\sqrt{2g}\,\tan\frac{\theta}{2}\int_0^H (H-h)\,h^{1/2}dh$$

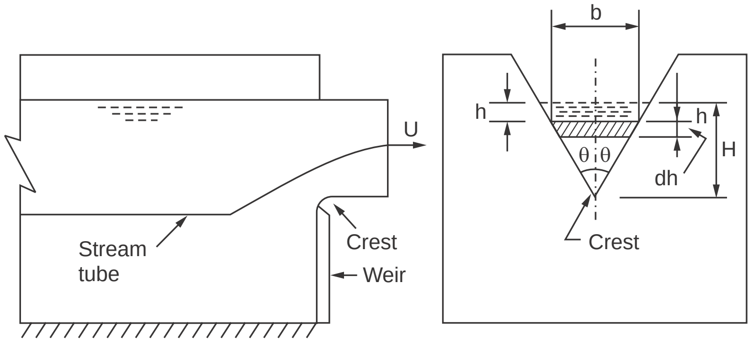

Figure 11.4.3 Triangular notch

$$Q = 2C_d\sqrt{2g}\,\tan\frac{\theta}{2}\left[\frac{Hh^{3/2}}{3/2} - \frac{h^{5/2}}{5/2}\right] = \frac{8}{15}C_d\,\sqrt{2g}\,\tan\frac{\theta}{2}\,H^{5/2} \qquad (11.4.3)$$

Table 11.4.1 A comparison of various flow measuring devices

Flow meter	Application	Accuracy	Pressure loss	Relative cost
Orifice	Clean, dirty liquids and some slurry	± 2 to 4% of the meter range	Medium	Low
Venturi meter	Clean, dirty and viscous liquids and some slurries	± 1% of meter range	Low	Medium
Flow nozzle	Clean and dirty liquids	± 1 to 2% of meter range	Medium	Medium
Pitot tube	Clean liquids	± 3 to 5% of meter range	Very low	Low
Elbow meter	Clean and dirty liquids and some slurries	± 5 to 10% of meter range	Very low	Low
Turbine meter	Clean and viscous liquids	± 0.25% of flow rate	High	High
Laser Doppler	Dirty, viscous liquids and slurries	± 5% of meter range	Nil	High
Rectangle and *V* notch	Clean and dirty liquids	± 2 to 5% of meter range	Very low	Medium

SOLVED PROBLEMS

Problem 11.1 *A pitot static tube is used to measure the velocity of air flowing through a duct. The manometer shows a difference in head of 5 cm of water. If the density of air and water are 1.13 kg/m^3 and 1000 kg/m^3* ***determine the velocity of air.*** *Assume the coefficient of the pitot tube as 0.98.*

Flow velocity, $$\mathbf{V} = C_v\sqrt{2gh_m[(\rho_m/\rho)-1]}$$

$$= 0.98\sqrt{2\times 9.81\times\left(\frac{1000}{1.13}-1\right)\frac{5}{100}} = \mathbf{28.86\ m/s}$$

Problem 11.2 *The difference in mercury level of a pitot static tube connected to a submarine is 20 cm.* ***Determine the speed of the submarine.*** *The density of sea water is 1019 kg/m^3. Assume C_v = 0.98*

Speed of the submarine,

$$\mathbf{V} = C_v\sqrt{2gh_m((\rho_m/\rho)-1)}$$

$$= 0.98\sqrt{2\times 9.81\times\left(\frac{13600}{1019}-1\right)\frac{20}{100}} = \mathbf{6.821\ m/s\ or\ 25.6\ kmph.}$$

Problem 11.3 *A pitot static tube is mounted on an aircraft travelling at a speed 300 kmph against a wind velocity of 20 kmph. If the specific weight of air is 12 N/m^3* ***determine the pressure difference the instrument will register.***

Aircraft velocity $= \frac{300\times 1000}{3600} = 83.33$ m/s,

Wind velocity $= \frac{20\times 1000}{3600} = 5.56$ m/s

Relative velocity of plane

$$V = 83.33 + 5.56 = 88.89 \text{ m/s}$$

Velocity recorded by pitot tube,

$$V = C_v\sqrt{2gh}$$

$88.89 = 0.98\sqrt{2\times 9.81\times h}$, Solving for, h which is head of air,

$\mathbf{h_{air} = 419.32\ m,}$ $\Delta P = 419.32 \times 12 =$ $\mathbf{5032\ N/m^2.}$

Problem 11.4 *The flow velocity of water in a pipe is measured by a pitot static tube. The tube is placed at the centre of a 30 cm diameter pipe. The difference between the stagnation and static pressures measured as head of mercury and converted to head of water is 10 cm. If the coefficient of velocity C_v = 0.98,* ***determine the velocity of water in the pipe.*** *If the mean velocity is 0.7 times the centre line velocity, compute the discharge of water through the pipe. The head causing the flow is given as head of the flowing fluid. Hence the equation used is*

Chapter 11

Centre line velocity $= C_v\sqrt{2gh} = 0.98\sqrt{2 \times 9.81 \times (10/100)}$ = **1.373 m/s**

Mean velocity in pipe = 0.7 × 1.373 = **0.961 m/s**

Discharge through the pipe, Q = Area of cross section × Mean velocity

$$\mathbf{Q} = \frac{\pi}{4} \times 0.3^2 \times 0.961 = \mathbf{0.068\ m^3/s\ or\ 68\ \mathit{l}/s}$$

Problem 11.5 *A pitot static tube is used to measure the velocity of air in a duct. The water manometer shows a reading of 8 cm. The static pressure in the duct is 9 kN/m² and the air temperature is 320 K. The local barometer reads 740 mm of mercury.* ***Calculate the air velocity if C_v*** *= 0.98. Assume the gas constant for air as 287 J/kg K.*

Atmospheric pressure $= \rho gh = (13.6 \times 10^3)(9.81)\left(\frac{740}{1000}\right) = 98.73$ kN/m²

∴ Static pressure in the duct = 98.73 + 9 = 107.73 kN/m² (absolute pressure)

Density of air inside the duct,

$$\rho = \frac{P}{RT} = \frac{107.73 \times 10^3}{287 \times 320} = 1.173 \text{ kg/m}^3$$

Differential pressure head = 8 cm of water $= \frac{8}{100} \times \frac{1000}{1.173}$ = 68.2 m of air

Air velocity $\mathbf{V} = C_v\sqrt{2gh_{air}} = 0.98\sqrt{2 \times 9.81 \times 68.2}$ = **35.85 m/s**

Problem 11.6 *A venturimeter of 150 mm × 75 mm size is used to measure the flow rate of oil having specific gravity of 0.9. The reading shown by the U tube manometer connected to the venturimeter is 150 mm of mercury column.* ***Calculate the coefficient of discharge*** *for the venturimeter if the flow rate is 1.7 m³/min. (Note : The size of venturimeter generally specified in terms of inlet and throat diameters)*

Refer equation (6.6.2)

Velocity $V_2 = \frac{C_d A_1}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh_m\left(\frac{\rho_m}{\rho} - 1\right)}$ and $Q = V_2 \times A_2$

Flow rate $Q = \frac{C_d A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh_m\left(\frac{\rho_m}{\rho} - 1\right)}$

Inlet area $A_1 = \frac{\pi}{4} \times 0.15^2 = 0.0177$ m²,

Throat area $A_2 = \frac{\pi}{4} \times 0.075^2 = 0.00442$ m²

Flow rate = (1.7/60) = 0.0283 m³/s, Substituting

$$0.0283 = \frac{C_d \times 0.0177 \times 0.00442}{\sqrt{0.0177^2 - 0.00442^2}} \sqrt{2 \times 9.81 \times 0.15 \left(\frac{13.6}{0.9} - 1\right)}$$

∴ $\mathbf{C_d = 0.963}$

Problem 11.7 *A venturimeter is used to measure liquid flow rate of 7500 litres per minute. The difference in pressure across the venturimeter is equivalent to 8 m of the flowing liquid. The pipe diameter is 19 cm.* ***Calculate the throat diameter*** *of the venturimeter. Assume the coefficient of discharge for the venturimeter as 0.96.*

$$Q = C_d \frac{A_1 A_2 \sqrt{2gh}}{\sqrt{A_1^2 - A_2^2}},$$

$$A_1 = \frac{\pi}{4} \times 0.19^2 = 0.0284 \text{ m}^2$$

$$\frac{7500 \times 10^{-3}}{60} = \frac{0.96 \times 0.0284\ A_2}{\sqrt{0.0284^2 - A_2^2}} \sqrt{2 \times 9.81 \times 8}, \text{ Solving } A_2 = 0.0098 \text{ m}^2$$

Let the diameter be d, $\frac{\pi}{4} \times d^2 = 0.0098$

∴ $$\mathbf{d} = \sqrt{\frac{4 \times 0.0098}{\pi}} = \mathbf{9.9\ cm}$$

Problem 11.8 *A venturimeter is fitted in a pipe of 30 cm diameter inclined at 40° to the horizontal to measure the flow rate of petrol having a specific gravity of 0.8. The ratio of areas of main pipe and throat is 5 and the throat is at 1 m from the inlet along its length. The difference in manometer head is 40 mm of mercury. Assuming the coefficient of discharge as 0.96.* ***Calculate the discharge through the venturimeter*** *and the pressure difference between the throat and the entry point of the venturimeter.*

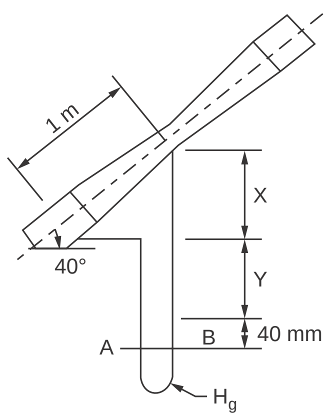

Figure P. 11.8

Refer equation 6.6.2 applicable for all orientations

$$Q = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh_m \left(\frac{\rho_m}{\rho} - 1\right)},\ A_1 = \frac{\pi}{4} \times 0.3^2 = 0.0707 \text{ m}^2$$

$A_1/A_2 = 5$

$\therefore$ $A_2 = 0.0707/5 = 0.0141$ m^2, Substituting,

$$\mathbf{Q} = \frac{0.96 \times 0.0141 \times 0.0707}{\sqrt{0.0707^2 - 0.0141^2}} \sqrt{2 \times 9.81 \times 0.04 \times \left(\frac{13.6}{0.8} - 1\right)}$$

$= \mathbf{0.0486\ m^3/s}$

Considering points A and B and level at A as datum

$$P_A + \rho gy + \rho g(0.04) = P_B + \rho gx + \rho gy + \rho_m g\ (0.04)$$

$$P_A - P_B = \rho gx + 0.04 \times g \times (\rho_m - \rho)$$

$$= \rho g\ (1 \times \sin 40) + 0.04 \times 9.81 \times (13600 - 800)$$

$$= 800 \times 9.81\ (1 \times \sin 40) + 0.04 \times 9.81 \times (13600 - 800)$$

$$= 10067.32 \text{ N/m}^2 \text{ or } 10.07 \text{ kN/m}^2$$

Problem 11.9 *A venturimeter of 20 cm × 10 cm size is calibrated in a laboratory using a right angled V notch. When a steady head of 0.187 m is maintained over the notch with a coefficient of discharge 0.6, the difference of head between he entrance and throat section of the Venturimeter is found to be 39 cm head of the fluid measured using notch as actual flow,* ***determine the discharge coefficient of venturimeter.***

Discharge over a triangular notch $Q = \frac{8}{15} C_D \sqrt{2g} \tan\frac{\theta}{2} h^{5/2}$

For right angled triangular notch, tan (θ/2) = tan 45° = 1

$\therefore$
$$Q = \frac{8}{15} \times 0.6 \times \sqrt{2 \times 9.81} \times 0.187^{5/2} = 0.02143 \text{ m}^3/\text{s}$$

For the venturimeter

$$Q = C_d \frac{A_1}{\sqrt{(A_1^2 / A_2^2) - 1}} \sqrt{2gh},\ A_1 = \frac{\pi}{4} \times 0.2^2 = 0.0314 \text{ m}^2$$

$$A_2 = \frac{\pi}{4} \times 0.1^2 = 0.0785 \text{ m}^2,$$

$$0.0214 = C_d \frac{0.0314}{\sqrt{(0.0314^2 / 0.00785^2) - 1}} \sqrt{2 \times 9.81 \times 0.39}$$

$\mathbf{C_d = 0.96}$

Problem 11.10 *A venturimeter with throat diameter 0.065 m and coefficient of discharge 0.95 is used to calibrate a pitot static tube. Air flows through a 110 mm diameter horizontal pipe in which the venturimeter is fitted. The difference in water level in the manometer attached to the venturimeter is 50 mm. The pitot static tube is placed downstream of the venturimeter and the water manometer attached to the pitot static tube shows a reading of 7 mm.* ***Calculate the flow rate through the pipe*** *and the coefficient of velocity of the pitot static tube. Assume the density of air as 1.13 kg/m³ and that of water as 1000 kg/m³.*

Flow rate through the venturimeter

$$Q = C_d \frac{A_1}{\sqrt{(A_1^2 / A_2^2) - 1}} \sqrt{2gh_m\left(\frac{\rho_m}{\rho} - 1\right)}$$

$$A_1 = \frac{\pi}{4} \times 0.11^2 = 0.0095 \text{ m}^2, \quad A_2 = \frac{\pi}{4} \times 0.065^2 = 0.00332 \text{ m}^2$$

$$\mathbf{Q} = C_d \frac{0.95 \times 0.0095}{\sqrt{(0.0095^2 / 0.00332^2) - 1}} \sqrt{2 \times 9.81 \times 0.05\left(\frac{1000}{1.13} - 1\right)}$$

$$= \mathbf{0.0992 \ m^3/s}$$

∴ Mean velocity down stream, $V = 4 \times 0.0992/\pi \times 0.11^2 = 10.44$ m/s

Mean velocity measured by pitot static tube

$$V = C_v \sqrt{2gh_m\left(\frac{\rho_m}{\rho} - 1\right)}$$

$$10.44 = C_v \sqrt{2 \times 9.81 \times 0.007\left(\frac{1000}{1.13} - 1\right)}$$

∴ $\mathbf{C_v = 0.95}$

Problem 11.11 *A venturimeter with throat diameter 5 cm and coefficient of discharge 0.96 is fitted in a pipeline which carries water in it. The pressure difference across the venturimeter is 12 N/m². If an orifice meter with 5 cm diameter is futted in the same pipe line,* ***determine the coefficient of discharge of*** *the orifice meter, if the pressure difference across it is 28 N/m².*

Flow rate in venturimeter

$$Q_v = C_d \frac{A_1}{\sqrt{(A_1^2 / A_2^2) - 1}} \sqrt{2gh}$$

$$h = \frac{P}{\rho g} = \frac{12}{1000 \times 9.81},$$

$$Q = 0.96 \frac{A_1}{\sqrt{(A_1^2 / A_2^2) - 1}} \sqrt{2 \times 9.81 \times \left(\frac{12}{1000 \times 9.81}\right)}$$

Flow rate through the orifice

$$Q_0 = C_d \frac{A_1}{\sqrt{(A_1^2 / A_2^2) - 1}} \sqrt{2gh}$$

Since the throat diameter of venturi and orifice are the same cancelling common terms

$$0.96 \sqrt{2 \times \frac{12}{1000}} = C_d \sqrt{2 \times 9.81 \times \frac{28}{1000 \times 9.81}}$$

Simplifying $\quad 0.149 = C_d \times 0.237 \quad \therefore \mathbf{C_d} = \frac{0.149}{0.237} = \mathbf{0.63}$

Problem 11.12 *Water flows in an elbowmeter creating a pressure difference of 10 kN/m² between its outer and inner wall. The elbowmeter is fitted in a vertical pipe of 15 cm diameter. If the tapping point at the outer wall of the elbowmeter is 5 cm higher than the tapping point at the innerwall.* ***Calculate the flow rate through*** *the elbowmeter.*

The pressure loss in elbowmeter is (suffices i and o indicate inside and outside)

$$\Delta P = \left(\frac{P_0}{\rho g} + y_0\right) - \left(\frac{P_i}{\rho g} + y_i\right)$$

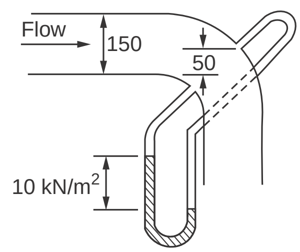

Figure P. 11.12

Also pressure loss can be expressed in terms of the flow velocity in the bend as

$$\Delta P = k \frac{V^2}{2g}$$

$$\therefore \quad k \frac{V^2}{2g} = \left(\frac{P_0}{\rho g} + y_0\right) - \left(\frac{P_i}{\rho g} + y_i\right)$$

$$V = \sqrt{\frac{2g}{k}\left[\left(\frac{P_0}{\rho g} + y_0\right) - \left(\frac{P_i}{\rho g} + y_i\right)\right]}$$

$\therefore$ Discharge through the elbowmeter

$$Q = A \times V = A \sqrt{\frac{2g}{k}\left[\left(\frac{P_0}{\rho g} + y_0\right) - \left(\frac{P_i}{\rho g} + y_i\right)\right]}$$

Assuming $k = 1$

$$\mathbf{Q} = C_d A \sqrt{2g\left[\left(\frac{P_0 - P_i}{\rho g} + (y_0 - y_i)\right)\right]}$$

$$= 0.6 \times \frac{\pi}{4}\, 0.15^2 \sqrt{2 \times 9.81 \left[\frac{10 \times 10^3}{1000 \times 9.81} + 0.05\right]} = \mathbf{0.0486\ m^3/s}$$

Problem 11.13 *The actual velocity of a liquid issuing through a 7 cm diameter orifice fitted in an open tank is 6 m/s under a head of 3 m. If the discharge measured in a collecting tank is 0.020 m*^{3}*/s,* ***calculate the coefficient of velocity,*** *coefficient of contraction and the theoretical discharge through the orifice.*

Flow velocity in orifice $= V = C_v\sqrt{2gh}$, $6 = C_v\sqrt{2\times 9.81\times 3}$

Coefficient of velocity $\mathbf{C_v = 0.9124}$ ∴ Actual discharge $Q = C_d\sqrt{2gh}$

$$0.020 = C_d\,\frac{\pi}{4}\times\left(\frac{7}{100}\right)^2\times\sqrt{2\times 9.81\times 3}$$

Coefficient of discharge

$$C_d = 0.6774$$

Coefficient of contraction

$$= \mathbf{C_c} = \frac{C_d}{C_v} = \frac{0.6774}{0.9124} = \mathbf{0.7424}$$

Problem 11.14 *Water is discharged through a 15 cm diameter orifice in the vertical side of an open tank at the rate of 190 litres per second. Water stands 15 m above the centerline of the orifice. A point on the jet measured from the vena contracta has co-ordinates 5 m horizontal and 0.5 m vertical.* ***Find the hydraulic coefficients*** C_v***,*** C_c ***and*** C_d **of the orifice.**

Actual discharge $\quad Q = C_d A\sqrt{2gh}$

$$190\times 10^{-3} = C_d\times\frac{\pi}{4}\times 0.15^2\times\sqrt{2\times 9.81\times 15},\ \mathbf{C_d = 0.627}$$

Let the jet travel during time t horizontally through a distance x and the jet fall by distance y during this time.

$$\therefore\quad x = V\times t = C_v\sqrt{2gh}\,t \text{ or } x^2 = C_v^2\,2ght^2$$

$$y = (1/2)gt^2$$

$$\therefore\quad \frac{x^2}{y} = 4C_v^2 h$$

$$\therefore\quad C_v = \sqrt{\frac{x^2}{4yh}},$$

Here $x = 5$ m, and y = 0.5 m

$$\therefore\quad \mathbf{C_v} = \sqrt{\frac{5^2}{4\times 0.5\times 15}} = \mathbf{0.913}$$

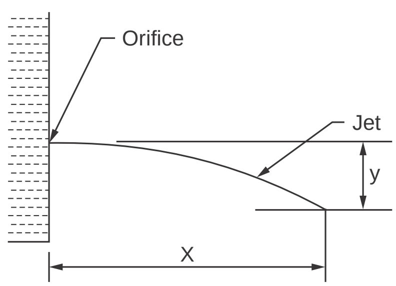

Figure P. 11.14

Coefficient of contraction,

$$\mathbf{C_c} = \frac{C_d}{C_v} = \frac{0.627}{0.913} = \mathbf{0.687}$$

Problem 11.15 *An orifice of 8 cm diameter is fitted in a 20 cm diameter pipe that carries oil of specific gravity 0.8. The mercury manometer attached to the orifice shows a reading of 0.75 m.* ***Calculate the oil flow rate*** *throught the pipe. Assume coefficient of discharge for orifice as 0.6.*

Flow rate $$Q = C_d \frac{A_1}{\sqrt{(A_1^2 / A_1^2) - 1}} \sqrt{2gh_m\left(\frac{\rho_m}{\rho} - 1\right)}$$

$$A_1 = \frac{\pi}{4} \times 0.2^2 = 0.0314 \text{ m}^2, \quad A_2 = \frac{\pi}{4} \times 0.08^2 = 0.00503 \text{ m}^2$$

$$\mathbf{Q} = \frac{0.6 \times 0.0314}{\sqrt{(0.0314^2 / 0.00503^2) - 1}} \sqrt{2 \times 9.81 \times 0.75\left(\frac{13600}{800} - 1\right)}$$

$$= \mathbf{0.047\ m^3/s = 47\ l/s}$$

Problem 11.16 *A rectangular notch is used to measure the flow rate of water in an open channel. The width of the rectangular notch is 3 m and the head of water causing the flow is 0.5 m.* ***Calculate the discharge assuming the coefficient of discharge*** *of the notch as 0.6.*

Discharge (Refer eqn 11.4.1) $$\mathbf{Q} = \frac{2}{3} C_d B \sqrt{2g}\, H^{3/2}$$

$$= \frac{2}{3} \times 0.6 \times 3\sqrt{2 \times 9.81} \times 0.5^{3/2} = \mathbf{1.88\ m^3/s}$$

Problem 11.17 ***What should be the width of a rectangular notch*** *that should be used to measure the water flow rate of 0.5 m^3/s in an open channel. The head causing the flow should not exceed half the notch width. Assume the coefficient of discharge of the rectangular notch as 0.6.*

Discharge $$Q = \frac{2}{3} C_d B \sqrt{2g}\, H^{3/2} \quad \text{or} \quad 0.5 = \frac{2}{3} \times 0.6 \times B\sqrt{2 \times 9.81}\left(\frac{B}{2}\right)^{3/2}$$

$$B^{5/2} = \frac{0.5}{0.626} = 0.799, \quad \mathbf{B = 0.914\ m}$$

Problem 11.18 *Water flow rate in an open channel is measured using a right angled V notch. The head of water over V notch is 0.15 m. Assuming the coefficient of discharge of the notch as 0.65,* ***calculate the discharge in the channel.***

As θ/2 = 45°, and tan (θ/2) = 1, the flow equation 11.4.3 reduces to

Discharge, $$\mathbf{Q} = \frac{8}{15} C_d \sqrt{2g}\, H^{5/2}$$

$$= \frac{8}{15} \times 0.65 \times \sqrt{2 \times 9.81} \tan 45 \times 0.15^{5/2} = \mathbf{0.0134\ m^3/s}$$

Problem 11.19 *Water flows over a right angled V notch at the rate of 0.045 m³/min maintaining a head of 0.048 m.* ***Calculate the coefficient of discharge*** *of the notch.*

Discharge $$Q = \frac{8}{15} C_d \sqrt{2g}\ \tan\frac{\theta}{2} H^{5/2}$$

$$\frac{0.045}{60} = \frac{8}{15} C_d \sqrt{2 \times 9.81}\ \tan 45 \times 0.048^{5/2}, \text{ Solving } \mathbf{C_d = 0.63}$$

Problem 11.20 *A right angled V notch is used to measure the flow rate in an open channel which carries water at the rate of 0.15 m³/s. If the maximum depth of water is not to exceed 1 m,* ***find the position of the apex of the notch from*** *the bed of the channel. Assume the coefficient of discharge as 0.6.*

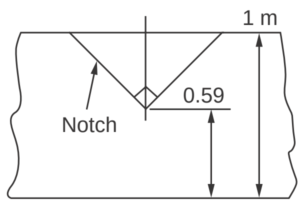

Figure P. 11.20

Discharge $$Q = \frac{8}{15} C_d \sqrt{2g}\ \tan\frac{\theta}{2} H^{5/2}$$

$$0.15 = \frac{8}{15} \times 0.6 \sqrt{2 \times 9.81}\ \tan 45 \times H^{5/2}$$

∴ **H = 0.41 m**

The distance of apex of *V* notch from the bed of channel

= Maximum depth of water – H = 1 – 0.41 = **0.59 m**

Problem 11.21 *An open channel is fitted with a rectangular and right angled V notch with coefficient of discharge 0.6 and 0.65 respectively. The width of rectangular notch is 0.5 m and the head causing the flow over it is 0.1 m.* ***Determine the head of water over*** *the V notch.*

Discharge through the rectangular notch,

$$Q = \frac{2}{3} C_d B \sqrt{2g} H^{3/2} = \frac{2}{3} \times 0.6 \times 0.5 \sqrt{2 \times 9.81}\ (0.1)^{3/2}$$

$$= 0.028 \text{ m}^3/\text{s}$$

Discharge through the *V* notch,

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan\frac{\theta}{2} H^{5/2}$$

$$0.028 = \frac{8}{15} \times 0.65 \sqrt{2 \times 9.81}\ \tan 45 \times H^{5/2} \quad \therefore \mathbf{H = 0.202\ m}$$

REVIEW QUESTIONS

1. Explain the principle involved in measuring velocity of flow using a pitot static tube.
2. Sketch and describe the construction details of a hot wire anemometer. Describe the methods of velocity measurement using it.
3. Discuss the method of velocity measurement using (*i*) Vane anemometer and (*ii*) Turbine meter.
4. Explain the method of velocity measurement using Laser Doppler anemometers.

Chapter 11

5. Derive the expression for computing discharge through a Venturimeter.
6. Compare the merits and demerits of flow measurement using Venturimeter, Orificemeter and nozzlemeter.
7. Define venacontracta. Derive the expression for flow measurement through an orifice in an open tank.
8. Derive an expression for the flow measurement in an open channel using rectangular notch.
9. Derive an expression for the flow measurement using a triangular notch in an open channel.
10. Compare the flow measuring devices with respect to their accuracy.

OBJECTIVE QUESTIONS

O Q.11.1 Fill in the blanks

1. Pitot static tube is used to measure _______________
2. In pitot static tube the opening perpendicular to the flow direction measures _______________
3. In pitot static tube the opening facing the flow direction measures _______________
4. Coefficient of velocity of orifice is the ratio of _______________
5. Coefficient of contraction is the ratio of _______________
6. Coefficient of discharge is the ratio of _______________
7. When a fluid flows though an elbow, higher pressure results at the _______________
8. The rotary movement in vane anemometer and current meter is created by the _______________
9. In turbine meter the rotor movement is sensed by a _______________
10. In a hot-wire anemometer, an _______________ is placed in a flowing stream.

Answers

1. Velocity of flow 2. Static pressure 3. Stagnation pressure 4. Actual velocity of jet at venacontracta to theoretical velocity 5. Area of the jet at venacontracta to the area of orifice 6. Actual flow/theoretical flow 7. Outerwall 8. Drag force on vanes and cones 9. Reluctance pickup coil 10. Electrically heated wire.

O Q.11.2 Select the correct answer

1. A pitot static tube is used to measure
   (*a*) Stagnation pressure
   (*b*) Static pressure
   (*c*) Dynamic pressure
   (*d*) Difference between the static pressure and dynamic pressure.
2. The more accurate flow measuring instrument is
   (*a*) Orificemeter (*b*) Venturimeter (*c*) Flowmeter (*d*) Elbow meter.
3. The range of coefficient of discharge for orifice meter is
   (*a*) 0.6 to 0.7 (*b*) 0.7 to 0.85 (*c*) 0.85 to 0.92 (*d*) 0.92 to 0.98.
4. Rotameter is used to measure
   (*a*) Viscosity (*b*) Flow (*c*) Density (*d*) Pressure.
5. Anemometer is used to measure
   (*a*) Velocity (*b*) Pressure (*c*) Viscosity (*d*) Density.
6. A *V* notch is used to measure
   (*a*) Velocity in a pipe (*b*) Wind velocity
   (*c*) Discharge of liquid in an open channel (*d*) Viscosity.

7. Flow rate in an open channel is more accurately measured using
   (*a*) Rectangular notch (*b*) Triangular notch
   (*c*) Venturi (*d*) Orifice.
8. Fluid velocity can be measured without disturbing the flow using
   (*a*) Pitot tube (*b*) Hot wire anemometer
   (*c*) Turbine meter (*d*) Laser Doppler anemometer.
9. Coefficient of discharge is the ratio of
   (*a*) Actual flow/Theoretical flow (*b*) Theoretical flow/Actual flow
   (*c*) Actual velocity/Theoretical velocity (*d*) Theoretical velocity/Actual velocity.
10. Current meter is used to measure
   (*a*) Pressure (*b*) Velocity (*c*) Density (*d*) Viscosity.

Answers

1. *c* 2. *b* 3. *a* 4. *b* 5. *a* 6. *c* 7. *b* 8. *d* 9. *a* 10. *b*

EXERCISE PROBLEMS

E 11.1 A water manometer attached to a pitot static tube used to measure air velocity shows a reading of 0.1 m. Assuming the ecoefficient of velocity as 0.98 and the density of air as 1.2 kg/m^3, calculate the air velocity. **(39.3 m/s)**

E 11.2 A pitot static tube is used to measure the velocity of water in a pipeline. If the mercury manometer attached to it shows a reading of 0.17 m, calculate the water velocity in the pipe. Assume coefficient of velocity as 0.98. **(6.3 m/s)**

E 11.3 A pitot static tube fitted in a pipe of 0.25 m diameter records the difference in stagnation and static pressure as 0.085 m of water. Assume the velocity coefficient as unity, calculate the water velocity in the pipe line. **(1.3 m/s)**

E 11.4 Air velocity in a duct is measured as 38.2 m/s by a pitot tube. Density of flowing air 1.3 kg/m^3. If the pressure difference recorded by the pitot static tube is 0.1 m of water, calculate the coefficient of velocity of the pitot static tube. **(0.98)**

E 11.5 Oil of density 800 kg/m^3 flows in a pipe of 0.2 m diameter at the rate of 0.06 m^3/s. A venturimeter with 0.1 m throat diameter is used to measure the flow rate of oil in the pipe. If the mercury manometer attached to it shows a reading of 0.18 m, calculate the coefficient of discharge of the Venturimeter. **(0.99)**

E 11.6 Oil of density 900 kg/m^3 flows through a pipe of 150 mm diameter. A venturimeter having throat of 100 mm diameter is fitted to the pipe line for measuring the flow rate of oil. A mercury manometer attached to it shows a reading of 200 mm. Assuming the coefficient of discharge for Venturimeter as 0.98, determine the oil flow rate. **(0.0064 m^3/s)**

E 11.7 A venturimeter with 0.08 m throat diameter is used to measure the flow in a pipe line of 0.16 m diameter. A mercury manometer attached to it shows deflection of 0.29 m. Assuming coefficient of discharge as 1, calculate the flow rate in the pipe. **(0.05 m^3/s)**

E 11.8 A pipe of 0.25 m diameter carries water at the rate of 7.2 m^3/s.The pressure head at the entry of the venturimeter, used to measure the flow rate in the pipe, is equivalent to 6 m of water. If the pressure head at the throat is zero, calculate the throat diameter of the venturi. **(0.12 m)**

E 11.9 Water flows in a pipe of 0.3 m diameter. A venturimeter with throat diameter 0.1 m is fitted in the pipe line. If the pressure difference recorded is 19.4 m of water, calculate the discharge assuming the coefficient of the discharge as unity. **(0.15 m^3/s)**

E 11.10 Oil of density 800 kg/m^3 flows in a pipe of 0.25 m diameter. An orifice meter of 0.1 m diameter fitted in the pipe to measure the flow rate. A mercury manometer fitted across the orifice shows a reading of 0.8 m. Calculate the discharge through the pipe. Assume the coefficient of discharge of orifice as 0.65. **(0.082 m^3/s)**

E 11.11 An orifice meter of 0.15 m diameter is fitted in a 0.3 m diameter pipe to measure the flow rate of water through it. If the pressure difference across the orifice is 10 m of water head, calculate the discharge in the pipe. Assume the coefficient of discharge of the orifice meter as 0.59. **(0.15 m^3/s)**

E 11.12 An orificemeter with 5 cm diameter is used to measure the flow rate of liquid. Under a head of 4 m, the velocity of liquid at vena contracta is 7.5 m/s. If the actual discharge through the pipe is 8 l/s, calculate the coefficients of velocity, discharge and contraction. **(0.85, 0.46, 0.54)**

E 11.13 Oil of specific gravity 0.8 flows through a pipe of 0.25 m diameter. An orifice of 0.1 m diameter is fitted to the pipe to measure the flow rate. A mercury manometer fitted across the orifice records a reading of 0.8 m. Calculate the coefficient of discharge of the orifice meter if the flow rate measured by it is 0.082 m^3/s. **(0.65)**

E 11.14 A rectangular notch of 250 cm width is used to measure the flow rate of water in an open channel. If the actual flow rate is 1.16 m^3/s, under a head of 0.253 m determine the coefficient of discharge of the notch. **(0.62)**

E 11.15 Determine the coefficient of discharge of a rectangular notch of 0.8 m width used to measure the flow rate in an open channel. The head causing flow is 0.4 m. If the coefficient of discharge is 0.6, determine the flow rate. **(0.358 m^3/s)**

E 11.16 Water flows over a right angled *V* notch to a height of 0.2 m. Calculate the coefficient of discharge of the notch if the actual flow rate measured is 26.2 l/s. **(0.62)**

E 11.17 Water flows at the rate of 106 *l*/ sec in a open channel in which rectangular and *V* notches are fitted. The width of the rectangular notch is 100 cm and the head of water over it is 0.15 m. If the *V* notches is right angled calculate the coefficients of discharge of both rectangular and *V* notches. **(0.62, 0.59)**