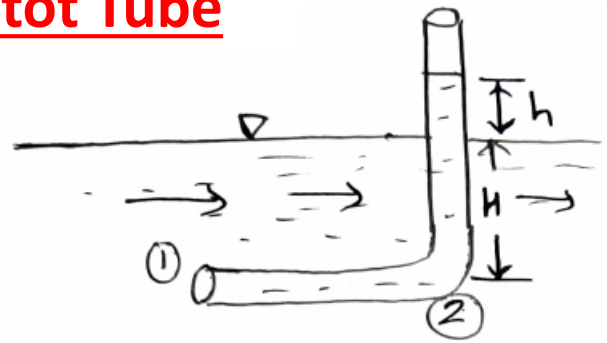
Fluid Measurement

Pitot Tube

The pitot tube can be used to measure the velocity of water in an open channel as well as in a closed pipe.

A bent L-shaped glass tube with both ends open is called a pitot tube.

Pitot Tube



Applying Bernoulli's eqⁿ at ① & ②

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + z_2$$

$$\Rightarrow H + \frac{v_1^2}{2g} = \frac{P_2}{\gamma} + 0$$

$$\Rightarrow H + \frac{v_1^2}{2g} = H + h$$

$$\Rightarrow v_1^2 = 2gh$$

$$\therefore v_1 = \sqrt{2gh}$$

[Here, $z_1 = z_2$ as ① & ② number point are in same level from datum]

[at point 2, $v_2 = 0$ because it is a stagnation point]

Kinetic energy will convert to potential energy

Now, $V_1 = \phi\sqrt{2gh_1}$; ϕ is pitot tube coefficient ; This coefficient takes into account the error due to turbulence & energy losses. The numeric value of this coefficient varies from 0·95 to 1·0.

Uses of Pitot Tube:

- It is used to measure speed of an aircraft
- It is used to measure speed of a boat
- It is used to measure fluid flows in different industries
- It is used where very high accuracy is not required
- It is used to measure flow profile in a duct or channel

Advantages:

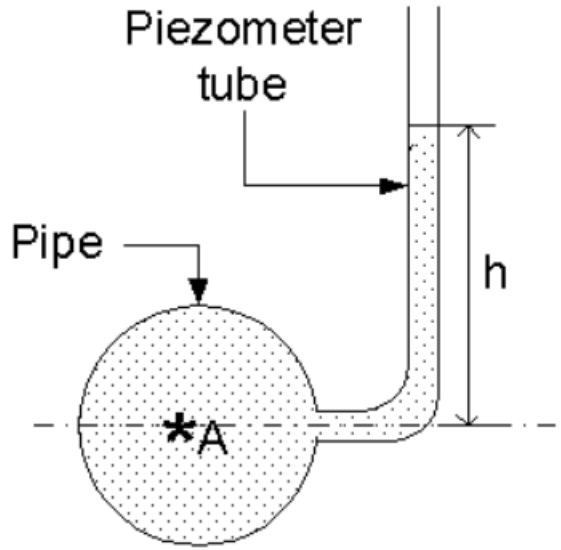
- Low cost
- Low permanent pressure loss
- size is small and contains no moving part
- Installation is easy
- can be used in different diameter pipes

Disadvantages:

- Low accuracy
- it is fragile
- low range ability
- solid particles can block pitot tube
- single point measurement

Piezometer

- A piezometer is an open tube that is used to measure pressure via the rise of fluid through column



$P = \rho g h$

Uses of Piezometer:

- To study the effect of water in pores of soil or rock is to reduce load bearing capacity of soil or rock. Effect is more pronounced with higher pore water pressure leading eventually in some cases to total failure of load bearing capacity of the soil.
- To determine level and flow pattern of ground water
- To determine the flow pattern of water in earth/rock fill, concrete dams, and their foundations.

Advantages:

- Simple and easy to use.
- Used to measure static pressure fluid in a container.
- used in measuring ground water level
- helpful in calculations to find performance of soil and rock.

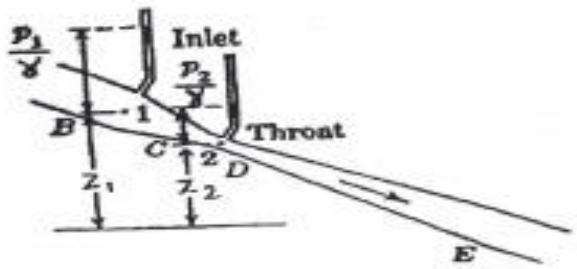
Disadvantages:

- Can not be used to measure the pressure of gaseous fluid.
- can not be used to measure pressure which is lower than atmospheric.
- can not be used when the value of pressure is very high.

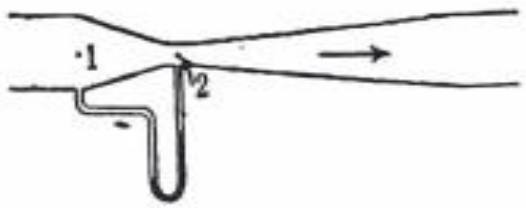
Venturimeter

Venturimeter is widely used for measuring discharge through a pipe, especially large discharges. It was invented by an American engineer, Clemens Herschel, in 1887 and was named by him in honor of the original discoverer of the principle involved, G. B. Venturi, an Italian philosopher.

A Venturimeter (Fig. 10.3) in its simple form consists of (i) a short converging cone BC connected to the approach pipe at the inlet end B, (ii) a cylindrical throat CD, and (iii) a gradually diverging cone DE connected to the pipe at the outlet end E. The Venturimeter may be horizontal, vertical or inclined, but it is generally kept horizontal. The Venturimeter must run full and it should be preceded by a straight length of pipe of not less than 5 to 10 diameters of pipe to reduce most of the turbulence in order to get accurate results. In order to avoid the tendency of fluid to separate at the throat due to increase in velocity and decrease in pressure, the ratio of the throat diameter to pipe diameter should be ¼ to ¾, the most suitable value being ⅓ to ½. The length of the divergent cone is made equal to 3 to 4 times the length of the convergent cone to reduce the frictional loss of head caused by turbulence as the velocity is reduced. When the frictional losses are of least consideration, the Venturimeter can be made with convergent and divergence angles up to 30^0 and 14^0 respectively. The size of a Venturimeter is expressed in terms of inlet and throat diameters, e.g. a 30 cm×10 cm Venturimeter fits a 30 cm diameter pipe and has a throat of 10 cm diameter.



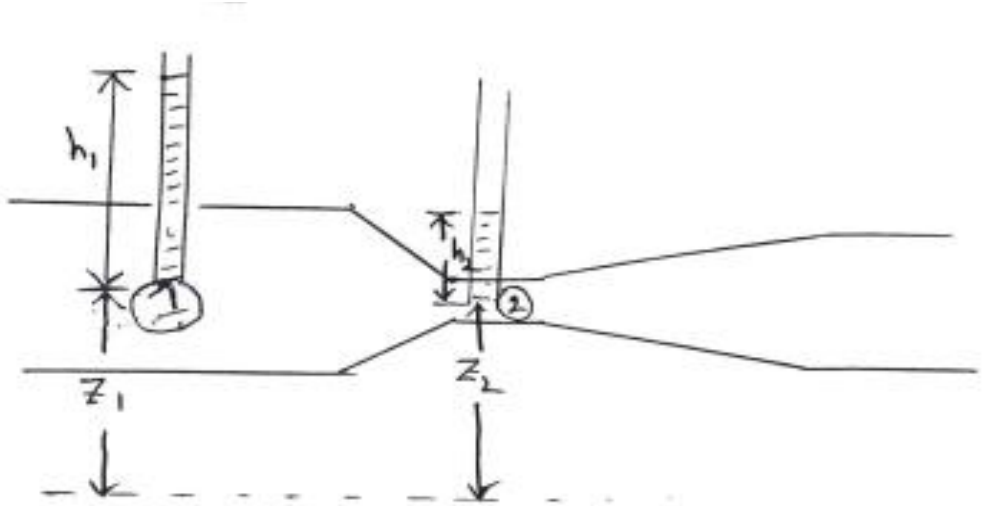
(a) Inclined Venturimeter



(b) Horizontal Venturimeter with differential manometer

Fig. 10.3 Venturimeter

Equation for Venturimeter



In section 2, the area is less,velocity is high, kinetic energy is high.So, pressure energy is less

Bernouli's eqn:

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

$$\Rightarrow \frac{P_1}{\rho g} - \frac{P_2}{\rho g} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \qquad [\because z_1 = z_2]$$

$$\Rightarrow h_1 - h_2 = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

$$\Rightarrow h = \frac{1}{2g}[v_2^2 - v_1^2]$$

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

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

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

$$\Rightarrow V_2 = \sqrt{\frac{2gh}{\frac{A_1^2 - A_2^2}{A_1^2}}}$$

$$\Rightarrow V_2 = \sqrt{\frac{2gh A_1^2}{A_1^2 - A_2^2}}$$

$$\Rightarrow v_2 = A_1\sqrt{\frac{2gh}{A_1^2 - A_2^2}}$$

$$\Rightarrow A_2 v_2 = A_1 A_2\sqrt{\frac{2gh}{A_1^2 - A_2^2}}$$

$$\therefore Q_t = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh} \qquad \text{...(10.8)}$$

The actual discharge Q_a of a Venturimeter will be less than the theoretical discharge Q_t given by Eq.(10.8) owing to the non-uniform distribution of velocity over the pipe section as well as friction and other losses. The theoretical discharge is therefore multiplied by a correction factor C_d, less than unity, to get the actual discharge Q_a or

$$Q_a = C_d \times Q_t \qquad (10.11)$$

The correction factor C_d is known as the *meter coefficient* or the *discharge coefficient*. It is best determined by measuring the actual flow Q through the Venturimeter by volume or weight, computing the theoretical flow Q_t from the manometer reading and the meter dimensions and computing the ratio of Q to Q_t. The value of C_d is affected by the ratio of A_1 to A_2, velocity, kinematic viscosity of fluid flowing and the roughness of the inner surface of the Venturimeter. However, the coefficient of a standard Venturimeter has a fairly constant value between 0.96 and 0.99.

In Eq.(10.8), the factor $\frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2g}$ is constant for a particular Venturimeter and is generally known as *Venturimeter constant*.

Uses of Venturimeter:

- Venturi meters are used in pipelines at wastewater collection systems and treatment plants.
- The temperatures and pressures of chemicals in a pipeline do not affect the accuracy of a Venturi flowmeter and because of this they are used in crude oil pipelines.
- The venturi in carburetors is used to measure airflow in a car engine and to ensure that a correct amount of fuel is fed to the gas combustion engine when needed during driving.

Advantages:

- Less pressure drop and higher coefficient of discharge
- It is flexible to installed (horizontal,inclined)
- High accuracy than any other device

Disadvantages:

- High cost and high maintanence is required
- can not be used in shorter length pipe

Orifice

Description

An orifice is an opening in the wall of a vessel through which a liquid flows. The usual purpose of an orifice is the measurement of flow. The orifices are classified according to their size, shape, shape of the upstream end and discharge condition as follows.

a) Size : Small and large orifices
b) Shape : Circular, rectangular, square and triangular orifices
c) Shape of the upstream end: Sharp-edged and rounded or bell-mouthed orifices
d) Discharge condition : Freely discharging and drowned or submerged orifices

Theoretical Velocity

Consider a vessel fitted with a vertical rounded orifice discharging water into the atmosphere under a head of H as shown in Fig. 10.4. The upper surface of the liquid in the vessel is also exposed to the atmosphere.

The liquid particles, in order to flow out through the orifice, move towards the orifice from all directions. Because of the inertia of these particles, they cannot make abrupt changes in their directions to reach the orifice and they therefore follow curvilinear paths that cause the jet to contract for a short distance after leaving the orifice. The section C-C where contraction of the jet is maximum is known as the *vena contracta*. For a sharp-edged orifice, the vena contracta is found to be at a distance of about one-half diameter downstream from the plane of the orifice. At the vena contracta, the streamlines are parallel to one another, the pressure is atmospheric and the velocity of liquid is maximum. Obviously, there is no contraction of the jet beyond the vena contracta,

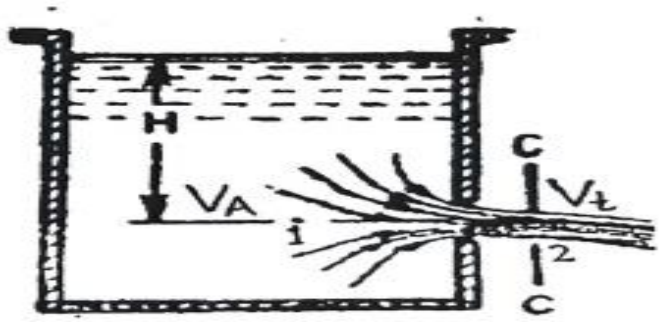


Fig. 10.4 Discharge from orifice

Since liquid particles at different elevations discharge through a vertical orifice under different heads, their velocities are not the same. In orifice flow, however, velocity is ordinarily taken as the velocity due to mean head H. The mean velocity thus obtained is represented by the symbol V_t, while the mean velocity in the channel of approach, called *velocity of approach*, is represented by V_A. Considering points 1 and 2 as shown in Fig. and applying the energy equation between them, we obtain

Coefficient of Velocity

The actual velocity of the orifice jet at the vena contracta is less than the theoretical velocity, because of the frictional resistance that occurs as the liquid enters and passes through the orifice. The ratio of the actual mean velocity V of the jet at the vena contracta to the theoretical velocity V_t at the vena contracta that would occur without friction is called the coefficient of velocity and is designated by C_v. Thus,

$$C_v = \frac{V}{V_t} \quad \text{and} \quad V = C_v V_t \qquad (10.15)$$

The value of C_v varies from 0.95 to 0.99, the average value being 0.97. The value of C_v generally increases with the head under which the flow takes place.

Coefficient of Contraction

The ratio of the cross-sectional area of the jet at the vena contracta to the area of the orifice is called the coefficient of contraction. If a and A represent respectively the cross-sectional area of the jet at the vena contracta and the area of the orifice and C_c is the coefficient of contraction, then

$$C_c = \frac{a}{A} \quad \text{or} \quad a = C_c A \tag{10.16}$$

The theoretical value of C_c is $\pi/(\pi + 2) = 0.611$, but in practice its value varies from 0.61 to 0.69, depending on the size and shape of the orifice and available head of the liquid under which the flow takes place. An average value of C_c is about 0.64.

Theoretical and Actual Discharges

If V_t be the theoretical velocity given by Eq.(10.14) and A be the cross-sectional area of the orifice, then the theoretical discharge through the orifice is given by

$$Q_t = AV_t = A\sqrt{2gH} \tag{10.17}$$

On the other hand, if V be the actual mean velocity of the jet at the vena contracta, the actual discharge through the orifice is given by

$$Q = aV \tag{10.18}$$

Since $a = C_c A$ and $V = C_v V_t$, the above equation becomes

$$Q = C_c A \times C_v V_t = C_c A \times C_v \sqrt{2gH} = C_c C_v A\sqrt{2gH} \tag{10.19}$$

It is usual to replace the product $C_c C_v$ with a single coefficient C_d, called the coefficient of discharge. The equation for the actual discharge of a fluid through an orifice thus becomes

$$Q = C_d A\sqrt{2gH} = C_d Q_t \tag{10.20}$$

Coefficient of Discharge

The ratio of the actual discharge through an orifice to the theoretical discharge is known as the coefficient of discharge Cd

$$C_d = \frac{Actual\ discharge}{Theoretical\ discharge} = \frac{Q_a}{Q_t} \qquad (10.21)$$

and comparing Eqs.(10.19) and (10.20), we obtain

$$C_d = C_c C_v \qquad (10.22)$$

The value of C_d varies with the values of C_v and C_c. It varies from 0.59 to 0.65 depending upon the shape and size of the orifice, the head of liquid under which the flow takes place, the approach conditions and the viscosity of the fluid. An average value of C_d is about 0.62.

(10.28)

Experimental Determination of Orifice Coefficients

(1) Determination of the coefficient of discharge C_d: The coefficient of discharge C_d is of greatest value to the engineers. From Eqs. (10.17) and (10.21), we get

$$C_d = \frac{Actual\ discharge}{Theoretical\ discharge} = \frac{Q_a}{Q_t} = \frac{Q_a}{A\sqrt{2gH}} \qquad (10.29)$$

The simplest method of determining C_d is by measuring the actual discharge through the orifice, the area of the orifice and the total head, and then using Eq.(10.29).

(2) Determination of the coefficient of velocity C_v: The coefficient of velocity C_v can be obtained from the equation

$$C_v = \frac{V}{\sqrt{2gH}} \qquad (10.30)$$

if the velocity of the jet at the vena contracta V and the total head H are determined. The velocity of the jet at the vena contracta can be computed from the area of the jet and the measured discharge Q. It can also be determined with fair accuracy with a Pitot tube or by the coordinate method presented below.

The Coordinate Method of Determining C_v

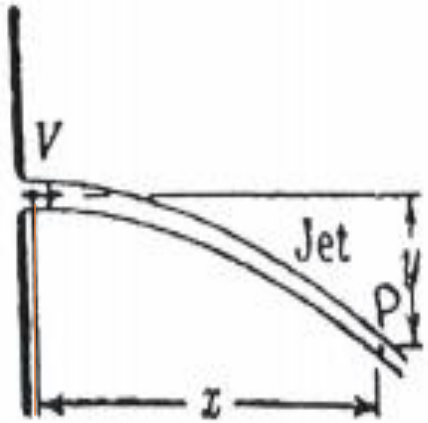
Figure 10.5 represents a side view of a jet from an orifice. The jet at the vena contracta is traveling horizontally with a velocity V. The force of gravity causes the jet to move downward. Let x and y be the coordinates of any other point P in the jet. Neglecting air resistance, the horizontal component of the jet velocity is constant with the time t, from which

$$x = Vt$$

The jet has a downward acceleration which conforms to the law of falling bodies from which

$$y = \frac{1}{2} g t^2$$

Eliminating t between the above two equations



x is the distance of P from vena contracta

Fig. 10.5 Determination of C_v by coordinate method

$$x^2 = \frac{2V^2}{g} y \qquad (10.31)$$

which is the equation of a parabola with its vertex at the vena contracta. It is thus obvious that the path of a jet from a vertical orifice is a parabola.

Solving Eq.(10.31) for V, we get

$$V = \sqrt{\frac{gx^2}{2y}} \qquad (10.32)$$

Now, the theoretical velocity of jet is

$$V_t = \sqrt{2gH}$$

$$\therefore \text{ The coefficient of velocity, } C_v = \frac{V}{V_t} = \sqrt{\frac{x^2}{4yH}} \qquad (10.33)$$

(3) Determination of the coefficient of contraction C_c: The coefficient contraction may be found by measuring the area of the jet at the vena contracta, and then dividing the same by the area of the orifice, i.e.

$$\text{Coefficient of contraction, } C_c = \frac{\textit{Area of the jet at the vena contracta}}{\textit{Area of the orifice}} = \frac{a}{A} \qquad (10.34)$$

It is often difficult to locate the vena contracta exactly and measure the area of the at the vena contracta accurately. Therefore, it is recommended that the coefficient contraction C_c be determined using the relation

$$C_c = \frac{C_d}{C_v} \qquad (10.35)$$

Advantages of Orifice:

- easy to install
- easy to maintain
- low cost
- measure wide range of flow

Disadvantages of Orifice:

- requires homogeneous fluid
- will be a pressure drop in case of orifice operation
- accuracy is affected by density,pressure and viscosity of fluid

Uses of Orifice:

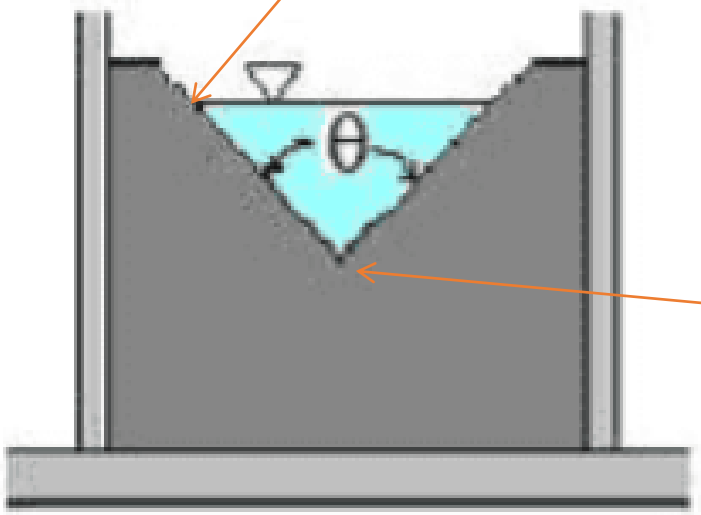
- Fluid flow rates in a pipe can be measured
- It is used in natural gas plants and water treatment plants
- Petrochemicals and refineries
- It is used in the oil filtration plant

Mouthpiece

- It has been determined experimentally that if a short pipe is fitted to an orifice, it will increase the discharge through the orifice by increasing the value of the coefficient of discharge. Such a pipe, whose length is generally more than 2 times the dia of the orifice and is fitted to the orifice externally or internally is known as mouthpiece. The mouthpieces are used to increase the discharge by making them run full of water and increasing the coefficient of contraction.

Notch	Weir
1. A notch may be defined as an opening provided in one side of a tank or reservoir with u/s liquid level below the top edge of the opening	1.A weir may be defined as a structure constructed across a river or canal to store water on the upstream side
2. Bottom edge of notch through which water flows is known as sill or crest.	2.The top weir over which water flows is called crest.
3.It is used to measure small discharge.	3.It is used to measure large discharge.
4.It is small size	4.It is usually large size.
5. It is made of metallic plate.	5.It is made of cement concrete or masonary.

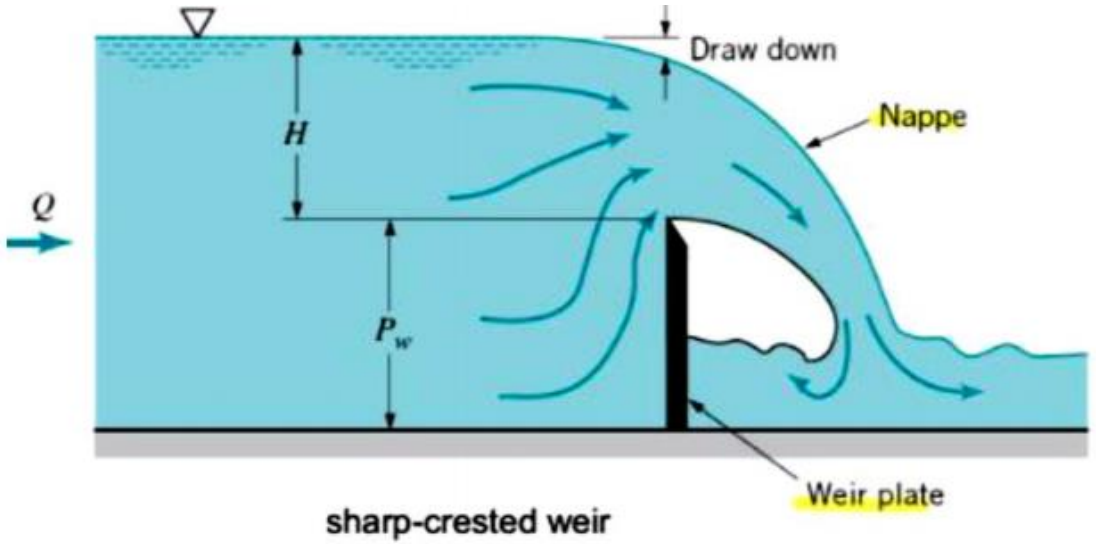
u/s side liquid is below the top edge

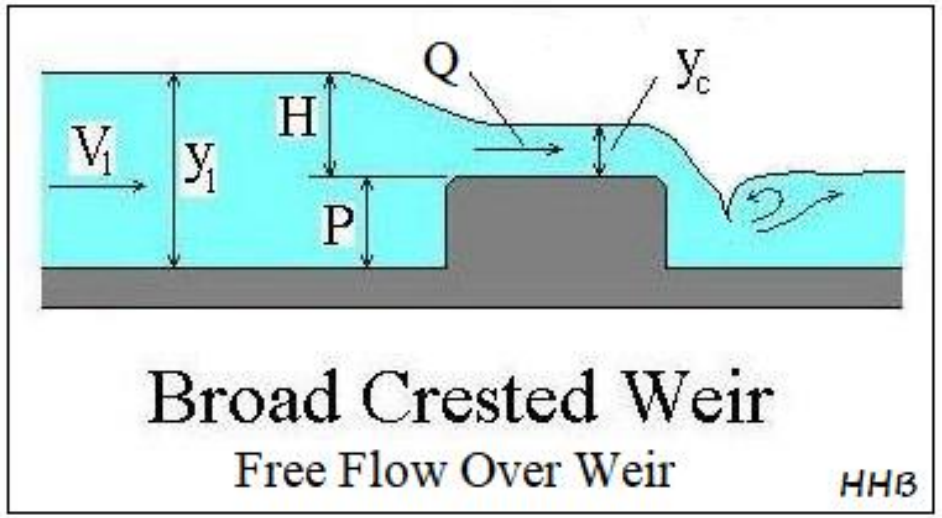


sill or crest

Notch

Broad and Sharp Crested Weir





Weirs

Description

A weir (Fig. 10.10) is an overflow structure built across an open channel to measure the flow. Weirs may be rectangular, triangular, trapezoidal, circular, parabolic or any other regular form. The edge or top surface with which the flowing liquid comes in contact is termed the *crest* of the weir. Classified with reference to the form of the crest, weirs may be *sharp-crested* or *broad-crested*. The sharp-crested weir has a sharp upstream edge so formed that the liquid in passing touches only a line. The broad-crested weir has either a sharp upstream edge or a crest so broad that the liquid in passing comes in contact with a surface.

The flow over a weir may be either *free* or *submerged*. If the water surface downstream from the weir is lower than the crest, the flow is free. If the downstream water surface is higher than the crest, the flow is submerged.

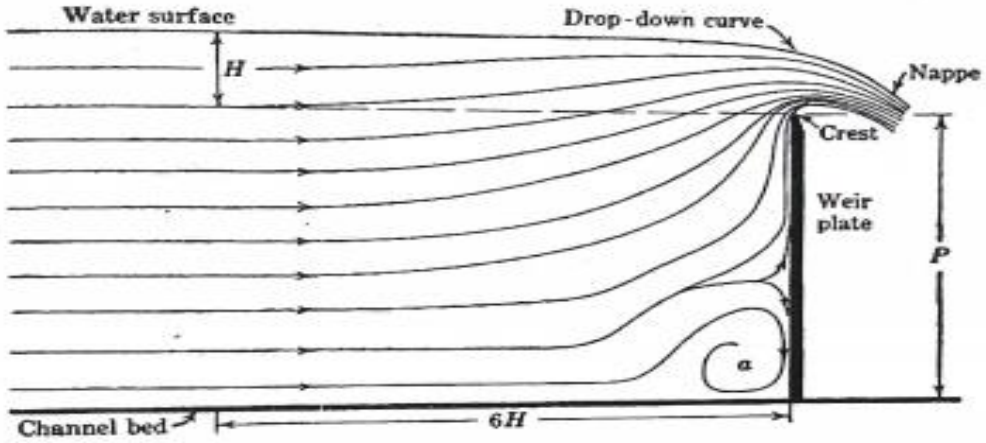


Fig. 10.10 Flow over a sharp-crested weir

The overflowing stream is termed the *nappe*. The nappe of a sharp-crested weir is contracted at its underside by the action of the vertical component of velocity just upstream from the weir. This is called *vertical* or *crest contraction*. If the sides of the weir also have sharp upstream edges so that the nappe is contracted in width, the weir is said to have end contractions. A weir having its width (transverse to the flow) equal to the width of the channel, so that only vertical contraction of the nappe takes places, is called a *suppressed or full-width weir*. When the width of the weir is less than the width of the channel so that the nappe contracts both in the vertical and lateral directions, the weir is termed a *contracted weir*.

There is a downward curvature of the surface of the liquid in the vicinity of the weir which is called the *drop-down curve*. The vertical distance H between the liquid surface and the crest of the weir, measured far enough upstream to be beyond the drop-down curve, is

called the *head*, and the mean velocity in this channel is called the *velocity of approach*. The height P of the weir is the vertical distance of the crest above the bottom of the channel.

Typical path lines of flow over a sharp-crested weir are shown in Fig. 10.10. The paths are approximately parallel until they reach a point about 6 times the head upstream from the weir. From this point they gradually curve upward to pass over the crest. There is a dead water region at the corner just upstream of the weir.

The crest of a sharp-crested weir is not necessarily knife-edged. In practice, the crest length of 1 mm to 2 mm in the direction of flow is provided and the downstream end is beveled at an angle of 45° to 60°. In this case, the flow springs clear of the weir body downstream of the weir and an air pocket is formed beneath the nappe from which air is continuously removed by the overflowing jet. As the flow continues, the pressure in the air pocket falls below the atmospheric pressure and the nappe is depressed. For flow measurement, the atmospheric pressure is maintained in the air pocket through the provision of air vents (Fig. 10.11).

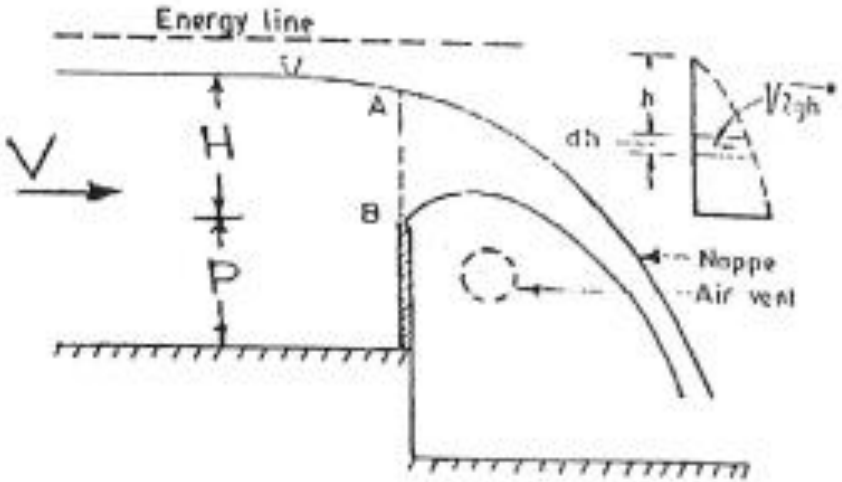


Fig. 10.11 Free flow over a rectangular sharp-crested suppressed weir

Equation of Rectangular Sharp-Crested Suppressed Weir:

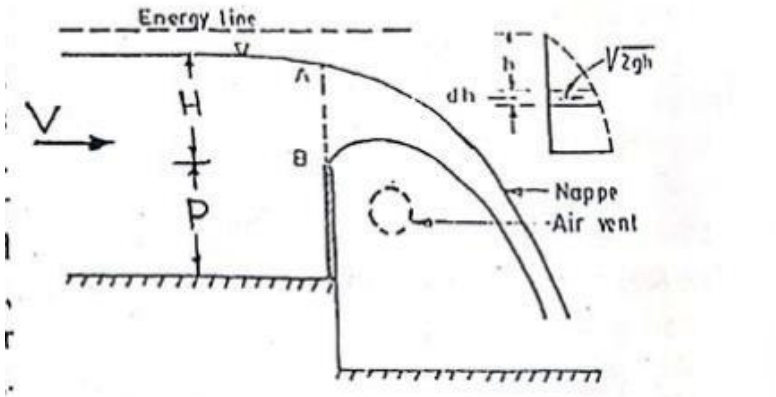


Fig. 10.10 Free flow over a rectangular sharp-crested suppressed weir

The variation of Cd for rectangular sharp-crested weir Is given with satisfactory accuracy using well-known Rehbok formula.

$$C_d = 0.611 + 0.08\ H/P$$

which is valid for $H/P \leq 5$.

$$Q = \frac{2}{3} C_d \sqrt{2g}\, b H^{1.5}$$


Secant
Lines
Tangent
Line
x+h
$f'(x) = \lim_{h \to 0} \frac{f(x+h) - f(x)}{h}$
$f(x) = \lim_{h \to 0}$
$= \lim_{h \to 0}$
$= \lim_{h \to 0}$
Math

Example 10.1

A Pitot tube is placed in water as shown in Fig. 10.1 and the liquid rises in the tube to a height of 10 cm above the water surface outside the tube. Calculate the velocity of stream upstream of the tube,

Solution Here, h = 10 cm = 0.10 m

The velocity of the stream upstream of the tube is

$$v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 0.10} = 1.40\ m/s$$

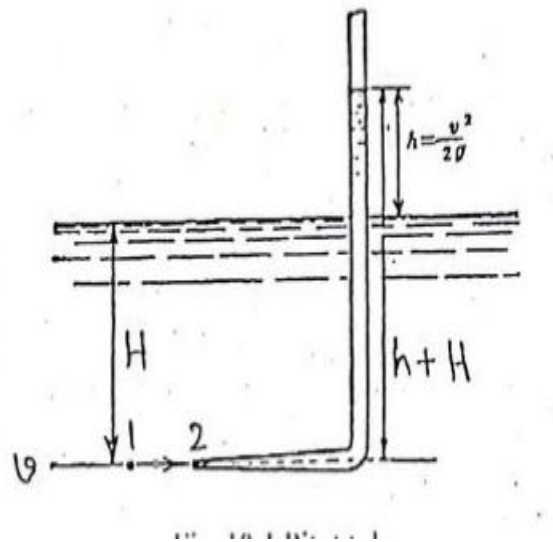


Fig 10.1

Example 10.2

A horizontal Ventuimeter having a throat 10 cm in diameter is installed in a 30 cm pipe and is used for measuring the flow of oil of specific gravity 0.9. The oil-mercury differential manometer shows a gauge difference of 20 cm. Calculate the actual discharge in liters per sec if the meter coefficient is 0.98.

Solution We have, $d_1 = 30$ cm $= 0.30$ m, $d_2 = 10$ cm $= 0.10$ m, Specific gravity of oil $= 0.9$,

Pressure difference $= 20$ cm, $C_d = 0.98$

Area at inlet, $A_1 = \frac{\pi}{4} \times d_1^2 = \frac{\pi}{4} \times 0.30^2 = 0.071\ m^2$

Area at throat, $A_2 = \frac{\pi}{4} \times d_2^2 = \frac{\pi}{4} \times 0.10^2 = 0.0079\ m^2$

Difference in pressure head, $h = 20$ cm of mercury

$$= \frac{20}{100}\left(\frac{13.6}{0.9} - 1\right) = 2.822\ m \text{ of oil}$$

$$\therefore Q_t = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh} = \frac{0.071 \times 0.0079}{\sqrt{0.071^2 - 0.0079^2}} \times \sqrt{2 \times 9.81 \times 2.822}$$

$$= 0.0588\ m^3/s = 58.80 \text{ liters/sec}$$

$$\therefore Q = C_d \times Q_t = 0.98 \times 58.80 = 57.63 \text{ liters/sec}$$

Example 10.3

A water main gives a pressure reading of 490 kN/m^2. Find the theoretical rate at which water in it is escaped through a circular orifice 2.5 cm in diameter.

Solution We have, p = 490 kN/m^2, Diameter of orifice, d = 2.5 cm = 0.025 m

We know that, $p = \gamma H$

$$\therefore H = \frac{p}{\gamma} = \frac{490}{9.81} = 49.59 \text{ m of water}$$

Theoretical velocity of flow through the orifice

$$V_t = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 49.59} = 31.30 \ m/s$$

$\therefore$ Theoretical rate of flow at which water is escaped through the orifice

$$Q_t = A \times V_t = \frac{\pi}{4} \times 0.025^2 \times 31.30 = 0.015 \ m^3/s$$

Example: A 60 cm diameter orifice is charging water under a head of 9 m. Calculate the actual discharge in liters per second and actual velocity of the jet at the vena contracta, if C_d = 0.62 and C_v=0.96

Solution

Given, d = 60 mm = 0.06 m, H = 9 m, C_d = 0.62, C_v = 0.96

Area of the orifice, $A = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times 0.06^2 = 0.00282\ m^2$

The theoretical discharge through the orifice is

$$Q_t = A\sqrt{2gH} = 0.00282 \times \sqrt{2 \times 9.81 \times 9} = 0.0375\ m^3/s = 37.50\ liters/\text{sec}$$

∴ The actual discharge through the orifice is

$$Q_a = C_d Q_t = 0.62 \times 0.0375 = 0.02323\ m^3/s = 23.23\ liters/\text{sec}$$

The theoretical velocity of the jet at vena contracta

$$V_t = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 9} = 13.29\ m/s$$

∴ The actual velocity of the jet at vena contracta

$$V = C_v V_t = 0.96 \times 13.29 = 12.76\ m/s$$

Example: Water flows through a circular orifice 2.5 cm in diameter in the side of a tank. The constant head of water above the center of the orifice is 75 cm. The coordinates of the centerline of the jet are 30 cm horizontally from the vena contracta and 3.2 cm vertically below the center of the orifice. The discharge from the orifice is 1.186 liters/sec. Find the orifice coefficients C_d, C_c and C_c.

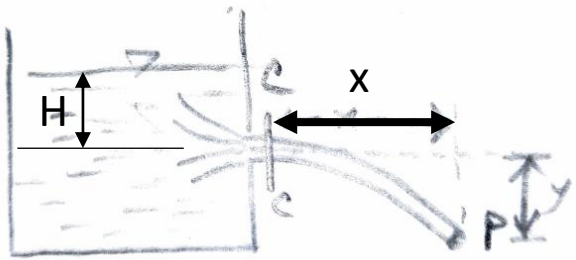
Solution Given, d = 2.5 cm = 0.025 m, H = 75 cm = 0.75 m, x = 30 cm = 0.30 m, y = 3.2 cm ≈ 0.032 m

x is the distance of point P from vena contracta

$$Q = 1.186 \text{ liters/sec} = 0.001186 \text{ m}^3/\text{s}$$

Area of the orifice, $A = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times 0.025^2 = 0.000491 \text{ m}^2$

Coefficient of discharge, $C_d = \frac{Q}{Q_t} = \frac{Q}{A\sqrt{2gH}} = \frac{0.001186}{0.000491 \times \sqrt{2 \times 9.81 \times 0.75}} = 0.63$



Coefficient of velocity, $C_v = \sqrt{\frac{x^2}{4yH}} = \sqrt{\frac{0.30^2}{4 \times 0.032 \times 0.75}} = 0.97$

C-C is the vena contracta

Coefficient of contraction, $C_c = C_d / C_v = 0.63/0.97 = 0.65$

ample 10.11

A rectangular sharp-crested weir spanning the full width of a rectangular channel 2 m de is 1 m high. Compute the discharge over the weir under an upstream head of 0.75 m.

lution Rectangular channel, b = 2 m, P = 1 m, H = 0.75 m

$$C_d = 0.611 + 0.08H/P = 0.611 + 0.08 \times 0.75/1 = 0.671$$

$$\therefore Q = \frac{2}{3} C_d \sqrt{2g}\, bH^{1.5} = \frac{2}{3} \times 0.671 \times \sqrt{2 \times 9.81} \times 2 \times 0.75^{1.5} = 2.574\ m^3/s$$

Rectangular Sharp Crested Contracted Weir

Self study

Rectangular sharp-crested contracted weir

In a contracted weir (Fig.10.12), the effective width of the weir (transverse to the direction of flow) is reduced and is given by the well-known *Francis formula*

$$B_e = B - 0.1nH \qquad (10.80)$$

where B is the width of the weir and n is the number of end contractions. The discharge equation for a contracted weir may be developed in the same way as for a suppressed weir. However, Kindsvater and Carter (1957), based on their extensive experimental investigation, modified the theoretical equation so that it would apply to all rectangular sharp-crested weirs regardless of whether they are suppressed or contracted. The equation for discharge over a sharp-crested weir is

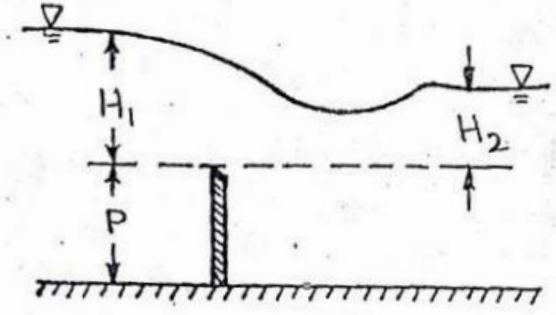


Fig. 10.11 Submerged sharp-crested weir

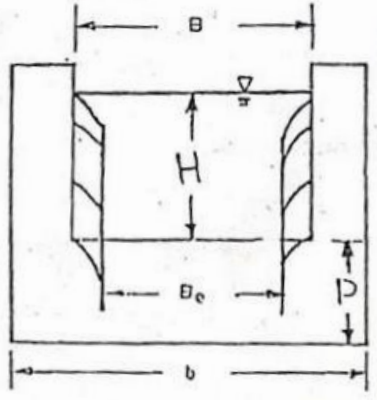


Fig. 10.12 Weir with end contractions

$$Q = \frac{2}{3} C_{de} \sqrt{2g}\, B_e H_e^{1.5} \qquad (10.81)$$

Self study

where C_{de} is the effective coefficient of discharge and B_e and H_e are the effective width and head of the weir, and

$$C_{de} = K_1 + K_2 \times \frac{H}{P} \quad (10.82a)$$

$$B_e = B + K_b \quad (10.82b)$$

$$H_e = H + K_h \quad (10.82c)$$

where the parameters K_b and K_h represent the combined effects of viscosity and surface tension on the flow. Usually K_h is taken to be equal to 0.001 m. The parameters K_1, K_2 and K_b, which depend on B/b, are given in Table 10.1.

Table 10.1 Values of K_1, K_2 and K_b for broad-crested weirs (Kindsvater and Carter, 1957)

B/b	K_1	K_2	K_b
1.0	0.602	0.0750	-0.0009
0.9	0.599	0.0640	0.0037
0.8	0.597	0.0450	0.0043
0.7	0.595	0.0300	0.0041
0.6	0.593	0.0180	0.0037
0.5	0.592	0.0110	0.0030
0.4	0.591	0.0058	0.0027
0.3	0.590	0.0020	0.0025
0.2	0.589	-0.0018	0.0024
0.1	0.588	-0.0021	0.0024

Self study

Example 10.12

Compute the discharge over a sharp-crested contracted weir 1 m wide and 1 m high set in a rectangular channel 2 m wide if the head over the weir is 0.75 m.

Solution We have, $b = 2$ m, $B = 1$ m, $P = 1$ m, $H = 0.75$ m, $K_h = 0.001$ m

$$\frac{B}{b} = \frac{1}{2} = 0.50$$

$\therefore$ From Table 10.1, $K_1 = 0.592$, $K_2 = 0.0110$ and $K_b = 0.0030$

$$\therefore C_{de} = K_1 + K_2 \times \frac{H}{P} = 0.592 + 0.0110 \times \frac{0.75}{1} = 0.60025$$

$$B_e = B + K_b = 1 + 0.0030 = 1.0030 \text{ m}$$

$$H_e = H + K_h = 0.75 + 0.001 = 0.751 \text{ m}$$

$$\therefore Q = \frac{2}{3} C_{de} \sqrt{2g}\, B_e H_e^{1.5} = \frac{2}{3} \times 0.60025 \times \sqrt{2 \times 9.81} \times 1.0030 \times 0.751^{1.5} = 1.161 \ m^3/s$$