

AIM OF THE EXPERIMENT

Verification of Bernoulli's theorem using Bernoulli's apparatus.

APPARATUS REQUIRED

1. A tank two-thirds full of water
2. Floating vessel or pontoon fitted with a sharp pointer moving on a graduated scale, with weights adjusted on a horizontal beam

THEORY

Bernoulli's law states that if a viscid fluid is flowing along a pipe of varying cross-section, then the pressure is lower at constrictions where the velocity is higher, and the pressure is higher where the pipe opens out and the fluid stagnates. The well-known Bernoulli's equation is derived under the following assumptions:

1. Fluid is incompressible.
2. Flow is steady.
3. Flow is frictionless.
4. The flow is a streamlined.

Then, it is expressed with the following equation,

$$\frac{P}{\rho g} + \frac{v^2}{2g} + z = h^* = \text{constant} \quad \dots(1)$$

where (in SI units):

p = fluid static pressure at the cross-section in N/m^2 .

ρ = density of the flowing fluid in kg/m^3

g = acceleration due to gravity in m/s^2 (its value is $9.81 \text{ m/s}^2 = 9810 \text{ mm/s}^2$)

v = mean velocity of fluid flow at the cross-section in m/s

z = elevation head of the centre of the cross-section with respect to a datum $z = 0$

h^* = total (stagnation) head in m

The terms on the left-hand side of the above equation represent the pressure head (h), velocity head (h_v), and elevation head (z), respectively. The sum of these terms is known as the total head (h^*). According to Bernoulli's theorem of fluid flow through a pipe, the total head h^* at any cross-section is constant (based on the assumptions given above). In a real flow due to friction and other imperfections, as well as measurement uncertainties, the results will deviate from the theoretical ones.

In our experimental setup, the centreline of all the cross-sections we are considering lies on the same horizontal plane (which we may choose as the datum, $z = 0$), and thus, all the ' z ' values are zeros so that the above equation reduces to:

$$P/\rho g + v^2/2g + z = h^* = \text{constant} \quad (\text{This is the total head at a cross-section})$$

For our experiment, we denote the pressure head as h_i and the total head as h_i^* where ' i ' represents the cross-section we are referring to.

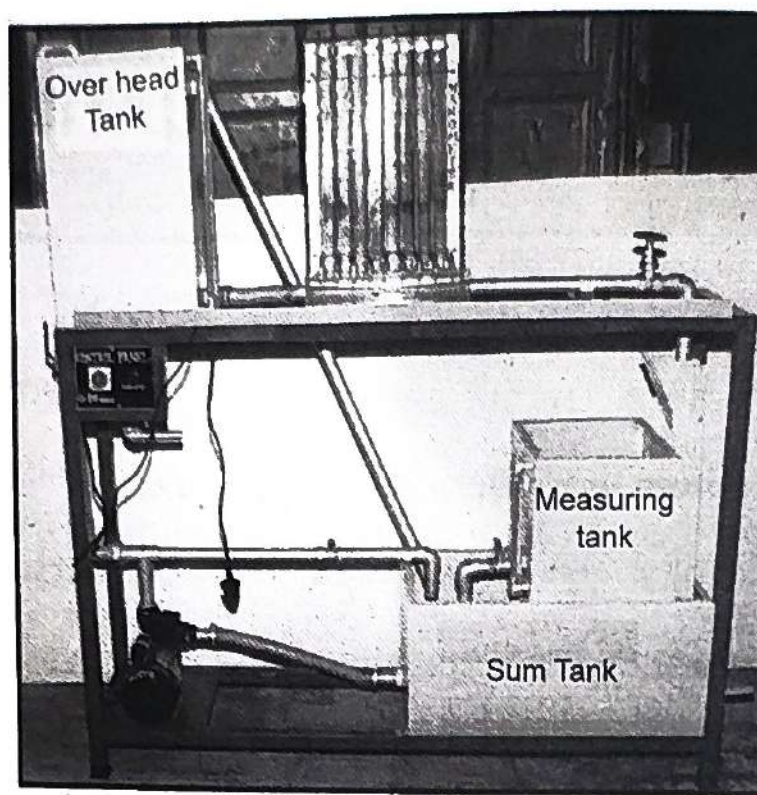


Fig. 1. Bernoulli's apparatus

PROCEDURE

1. Open the inlet valve slowly and allow the water to flow from the supply tank.
2. Now adjust the flow to get a constant head in the supply tank to make in flow and outflow equal.
3. Under this condition the pressure head will become constant in the piezometer tubes.
4. Measure the height of water level "h" (above the arbitrarily selected plane) in different piezometer tubes.
5. Compute the area of cross-section under the piezometer tubes.
6. Note down the quantity of water collected in the measuring tank for a given interval of time.
7. Change the inlet and outlet supply and note the reading.
8. Take at least two readings as described in the above steps.

OBSERVATIONS AND CALCULATIONS

Distance between each piezometer = 7.5 cm

Density of water = 0.001 kg/cm^3

1. Note down the Sl. No of Pitot tubes and their cross-sectional areas.
2. Volume of water collected $q = \dots\dots\dots \text{cm}^3$
3. Time taken for collection of water $t = \dots\dots\dots \text{s}$

Table 1: Data collection

Tube No.	Area of the flow (cm^2)	Discharge 'Q' (cm^3/s)	Velocity V (cm/s)	Velocity head (cm)	Pressure head (cm)	Total H (cm)

1. Discharge $Q = q / t = \dots\dots\dots \text{cm}^3/\text{s}$
2. Velocity, $V = Q / A = \dots\dots\dots = \dots\dots\dots \text{cm/s}$
where A is the cross-sectional area of the fluid flow.

3. Velocity head, $V^2/2g = \dots\dots\dots\text{cm}$
4. Pressure head (actual measurement or piezometer tube reading) $P/w = \dots\dots\dots\text{cm}$
5. Total Head $H = \text{Pressure head} + \text{Velocity Head} = \dots\dots\dots\text{cm}$

CONCLUSION

Bernoulli's theorem is experimented with and verified.

PRECAUTIONS

1. When the fluid is flowing, there is a fluctuation in the height of piezometer tubes. Note down the mean position carefully.
2. Carefully keep some level of fluid in the inlet and outlet supply tank.

POSSIBLE QUESTIONS

1. Briefly explain the various terms involved in Bernoulli's equation.

Ans. The first term in the Bernoulli equation represents the kinetic energy of the fluid, the second term represents the potential energy, and the third term represents the energy of fluid pressure.

2. What is a piezometer tube?

Ans. A piezometer is either a device used to measure liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device that measures the pressure (more precisely, the piezometric head) of groundwater at a specific point.

3. What are the applications of Bernoulli's theorem?

Ans. Applications of Bernoulli's theorem: (1) Dynamic lift on the wings of an aeroplane is due to Bernoulli's theorem. (2) Swinging a spring cricket ball is a consequence of Bernoulli's theorem. (3) During cyclones, the roofs of thatched houses will fly away.

4. What are the limitations of Bernoulli's equation?

Ans. Limitations of Bernoulli's equation are as follows:

- (a) The Bernoulli equation has been derived by assuming that the velocity of every element of the liquid across any cross-section of the pipe is uniform. Practically, it is not true. The elements of the liquid in the innermost layer have the maximum velocity. The velocity of the liquid decreases towards the walls of the pipe. Therefore, we should take into account the mean velocity of the liquid.
- (b) While deriving Bernoulli's equation, the viscous drag of the liquid has not been taken into consideration. The viscous drag comes into play when a liquid is in motion.
- (c) Bernoulli's equation has been derived on the assumption that there is no loss of energy when a liquid is in motion. Some kinetic energy is converted into heat energy and a part of it is lost due to shear force.
- (d) If the liquid is flowing along a curved path, the energy due to centrifugal force should also be taken into consideration.

5. Why is Bernoulli's theorem important?

Ans. Bernoulli's theorem is valid for any fluid (liquid or gas); it is especially important for fluids moving at a high velocity. Its principle is the basis of venturi scrubbers, thermo-compressors, aspirators, and other devices where fluids are moving at high velocities.

AIM OF THE EXPERIMENT

Determination of Darcy's friction factor for a given pipe and friction (major) losses in pipes as per IS 2951 (Part 1): 1965.

APPARATUS REQUIRED

1. Pipes of different diameters
2. U-tube manometer
3. Collecting tank with a piezometer
4. Stopwatch

THEORY

When the fluid is flowing through a pipe, it experiences some resistance due to which some of its energy is lost. This loss of energy in terms of the head is classified as

- Major Loss
- Minor Loss

Friction loss is considered a major loss and the most preferred equation to compute the head loss due to friction is the Darcy-Weisbach formula.

Darcy-Weisbach equation is

$$h_f = \frac{fLV^2}{2gD} \quad \dots(1)$$

where

h_f = head loss due to friction

f = coefficient of friction which is a function of Reynolds number

L = length of pipe

V = mean velocity of flow

D = diameter of the pipe

PROCEDURE

1. Note down the relevant dimensions, such as diameter and length of the pipe between the pressure tapping, area of collecting tank, etc.
2. Pressure tapping of a pipe is kept open while another pipe is closed.
3. The flow rate is adjusted to its maximum value by maintaining a suitable amount of steady flow in the pipe.
4. The discharge flowing in the circuit is recorded together with the water level in the left and right limbs of the manometer tube.
5. The flow rate is reduced in stages using a flow control valve. The discharge and the reading of the manometer are recorded.
6. This procedure is repeated by closing the pressure tapping of this pipe, together with other pipes, and for the opening of another pipe.

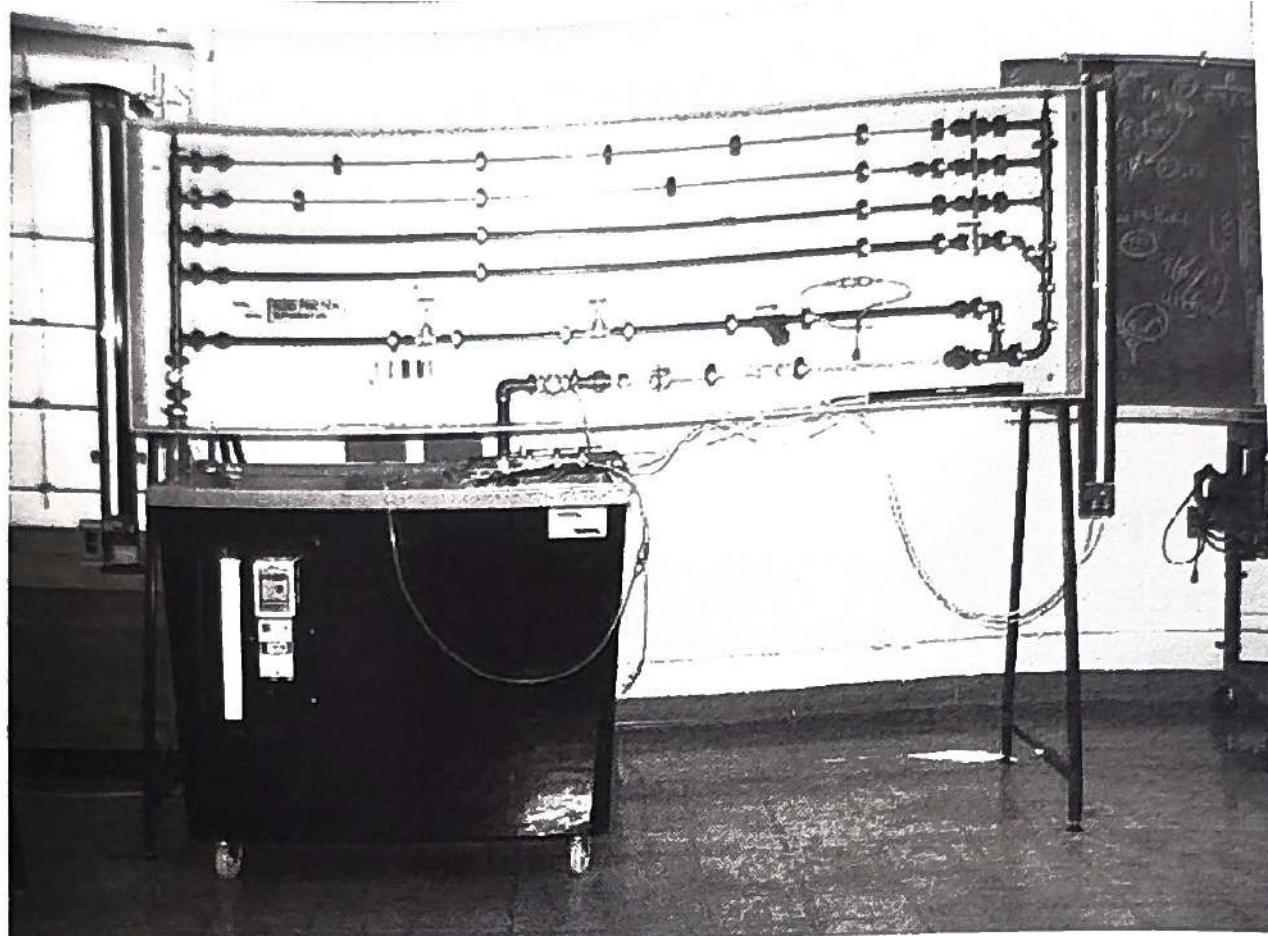


Fig. 1. Pipe friction apparatus

OBSERVATIONS AND CALCULATIONS

Diameter of pipe $D = \dots\dots\dots$

Length of pipe between pressure tapping $L = \dots\dots\dots$

Area of collecting tank = $\dots\dots\dots$

Table 1: Tabulation for collecting tank discharge

Sl. No.	Area of the tank (cm ²)	Rise of height in piezometer (cm)	Time of rising (s)	Velocity = Rise/time	Average velocity	$Q = \text{Area} \times \text{Avg vel}$
1.						
2.						
3.						

Table 2: Calculations for friction factor and flow type

Sl. No.	h_f	a (cm ²)	Velocity = Q/a	$f = \frac{2gDh_f}{LV^2}$	$Re = \frac{\rho v D}{\mu}$	Flow type

$$h_f = (\text{SP gravity of manometric fluid} / \text{SP gravity of water}) - 1$$

$$\text{Area of the pipe} = a = \pi/4(D^2)$$

$$\text{Velocity in the pipe} = Q/a$$

$$h_f = \frac{fLV^2}{2gD}$$

With all known variables, f can be calculated.

AIM OF THE EXPERIMENT

To determine the minor losses due to sudden enlargement, sudden contraction, and bend.

APPARATUS REQUIRED

1. A flow circuit of G.I. pipes of different pipe fittings, viz. large bend, small bend and elbow
2. Sudden enlargement from 25 mm diameter to 50 mm diameter
3. Sudden contraction from 50 mm diameter to 25 mm diameter
4. U-tube differential manometer
5. Collecting tank

THEORY

The local, or minor, head losses are caused by certain local features or disturbances. The disturbances may be caused by the size or shape of the pipe. This deformation affects the velocity distribution and may result in eddy formation.

Sudden Enlargement: Two pipes of cross-sectional area A_1 and A_2 flanged together with a constant velocity fluid flowing from a smaller diameter pipe. This flow breaks away from edges of narrow edges section, eddies form and the resulting turbulence causes dissipation of energy. The initiations and onset of disturbances in turbulence are due to fluid momentum and its area.

It is given by:
$$-h_{\text{exit}} = V^2/2g$$

...(1)

Eddy loss: Because the expansion loss is expended exclusively on eddy formation and continues the substance of rotational motion of fluid masses.

Sudden Contraction: It represents a pipeline in which abrupt contraction occurs. Inspection of the flow pattern reveals that it exists in two phases.

$$H_{\text{con}} = (V_c - V_2)^2/2g$$

...(2)

where, V_c is the velocity at vena contracta.

Losses at bends, elbows, and other fittings:

The flow pattern regarding separation and eddying in the region of separations in bends, and valves resulting head loss due to energy dissipation can be prescribed by the relation

$$h = KV^2/2g$$

...(3)

where V is the average flow velocity and the resistance coefficient K depends on the parameter defining the geometry of the section and flow.

Resistances of large sizes of elbows can be reduced appreciably by splitting the flow into several streams by a jet of guide vanes called cascades.

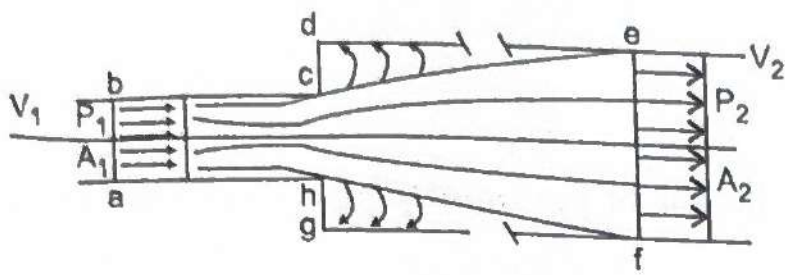


Fig. 1. Loss of head due to sudden enlargement

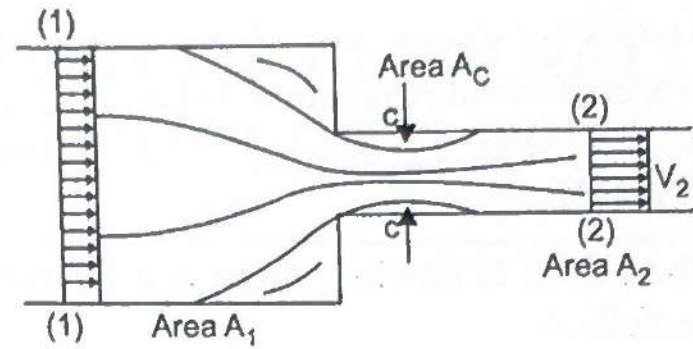


Fig. 2. Loss of head due to sudden contraction

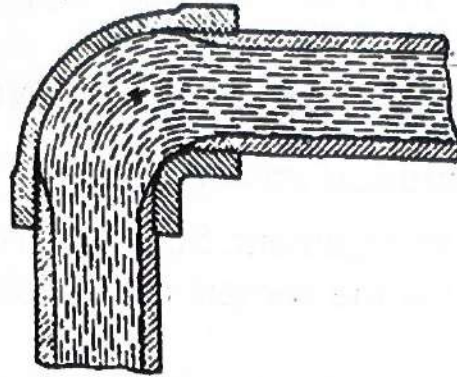


Fig. 3. Loss of head due to bend of the pipe

PROCEDURE

1. Note down the relevant dimensions, such as diameter and length of the pipe between the pressure tapping, area of collecting tank, etc.
2. Pressure tapping of a pipe is kept open while another pipe is closed.
3. The flow rate adjusted to its maximum value by maintaining a suitable amount of steady flow in the pipe.
4. The discharge flowing in the circuit is recorded together with the water level in the left and right limbs of the manometer tube.
5. The flow rate is reduced in stages using a flow control valve. The discharge and the reading of the manometer are recorded.
6. This procedure is repeated by closing the pressure tapping of this pipe, together with other pipes, and for the opening of another pipe.

OBSERVATIONS AND CALCULATION

Diameter of pipe, $D = \dots\dots\dots$

Length of pipe between pressure tapping $L = \dots\dots\dots$

Area of collecting tank = $\dots\dots\dots$

Type of the fitting = $\dots\dots\dots$

Table 1: Discharge measurement

Sl. No.	Manometer Reading			Discharge				Coefficient of loss $K = \frac{2g}{v^2} h_L$
	Left limb h_1	Right limb h_2	Difference of head in terms of water $h_f = 13.6 (h_2 - h_1)$	Initial	Final	Time (s)	Discharge (m^3/s)	
1.								
2.								
3.								

EXPERIMENT

2.6

DETERMINATION OF COEFFICIENT OF DISCHARGE FOR VENTURI METER

AIM OF THE EXPERIMENT

Determination of coefficient of discharge for venturi meter by IS 4477 (Part 2): 1975.

APPARATUS REQUIRED

1. Venturi meter, installed on pipes of different diameters
2. U-tube manometer
3. Collecting tank with a piezometer

THEORY

This device is used for measuring the fluid flow rate through a pipe. The Venturi meter consists of three parts as shown in Fig. 1.

1. Convergent cone
2. A cylindrical throat
3. Divergent cone

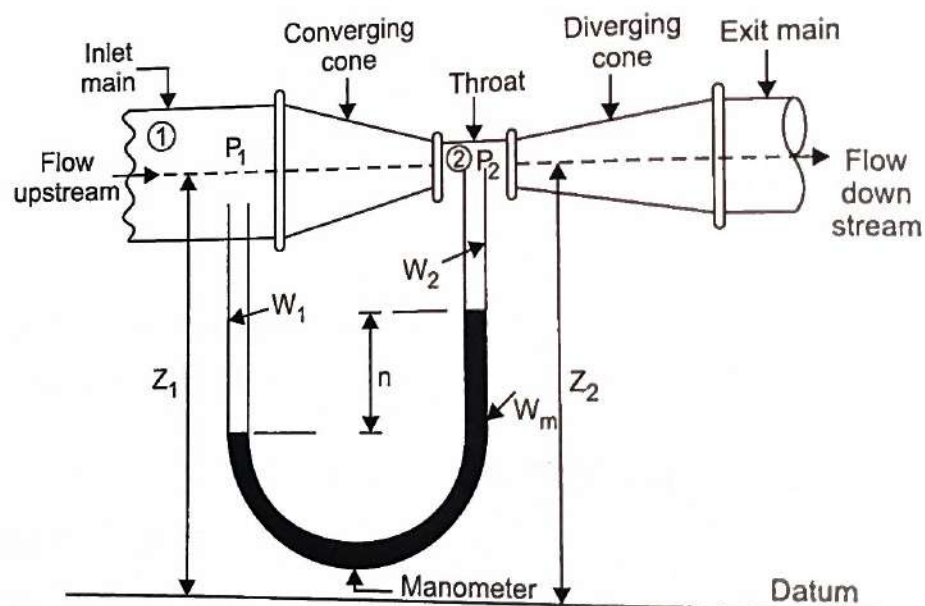


Fig. 1. Schematic diagram of venturi meter

WORKING PRINCIPLE

- The venturi meter works on the principle of Bernoulli's equation, i.e., the pressure decreases as the velocity increases.
- The cross-section of the throat is less than the cross-section of the inlet pipe.
- As the cross-section from the inlet pipe to the throat decreases, the velocity of the fluid increases, and hence the pressure decreases.
- Due to the decrease in pressure, a pressure difference is created between the inlet pipe and the throat.
- This pressure difference can be measured by applying a differential manometer between the inlet section and throat section or using two gauges on the inlet section and the throat.

AIM OF THE EXPERIMENT

Determination of coefficient of discharge for venturi meter by IS 4477 (Part 2): 1975.

APPARATUS REQUIRED

1. Venturi meter, installed on pipes of different diameters
2. U-tube manometer
3. Collecting tank with a piezometer

THEORY

This device is used for measuring the fluid flow rate through a pipe. The Venturi meter consists of three main parts as shown in Fig. 1.

1. Convergent cone
2. A cylindrical throat
3. Divergent cone

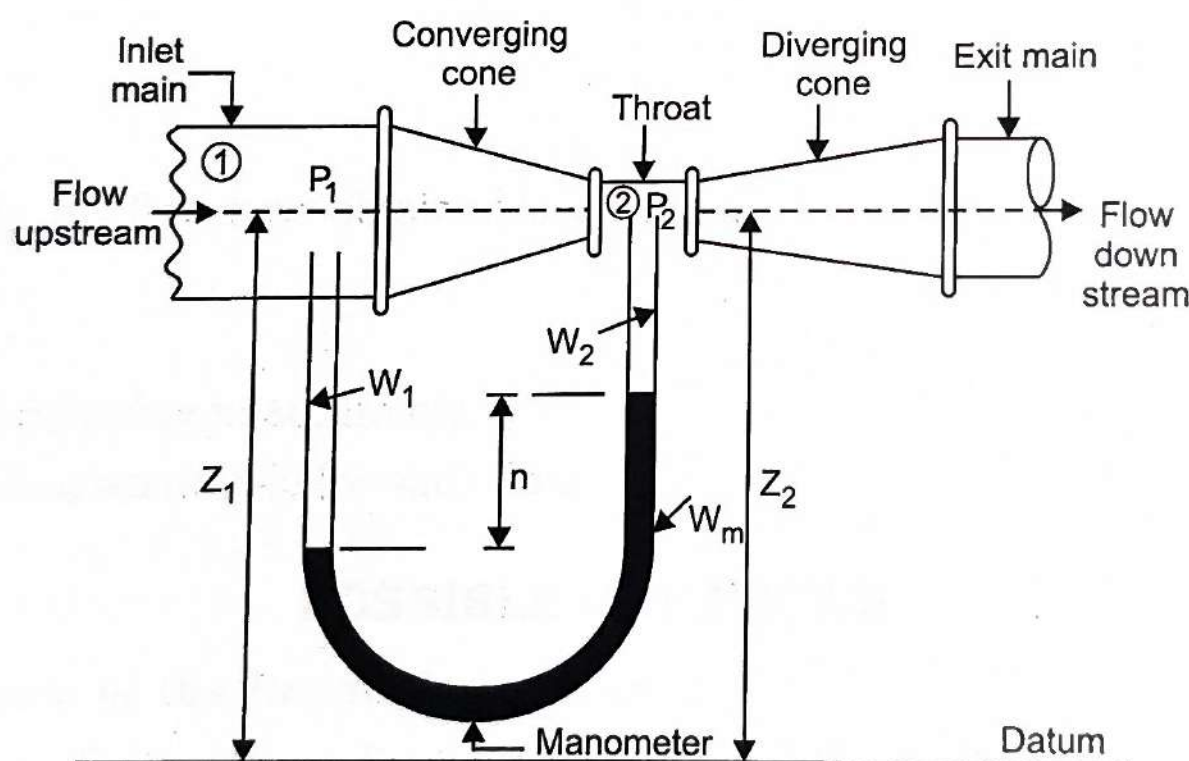


Fig. 1. Schematic diagram of venturi meter

WORKING PRINCIPLE

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- The cross-section of the throat is less than the cross-section of the inlet pipe.
- As the cross-section from the inlet pipe to the throat decreases, the velocity of the fluid increases, and hence the pressure decreases.
- Due to the decrease in pressure, a pressure difference is created between the inlet pipe and the throat.
- This pressure difference can be measured by applying a differential manometer between the inlet section and throat section or using two gauges on the inlet section and the throat.

- The pressure difference through the pipe is calculated after obtaining the flow rate.

Actual discharge, $Q_{act} = \frac{a \times h}{t} \left(\frac{m^3}{s} \right) \quad \dots(1)$

where a is the area of measuring tank in cm^2

h is height differences in piezometer in cm

t is time to collect water for a height difference of h cm, measured in seconds

Theoretical discharge is given by, $Q_{the} = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2g H_w}$... (2)

where A_1 is the area at the inlet side in cm^2

A_2 is the area at the throat in cm^2

H_w is head difference in the manometer, converted to cm of water

g is acceleration due to gravity (9.81 m/s^2)

Coefficient of discharge is given by, $C_d = \frac{Q_{act}}{Q_{the}}$... (3)

PROCEDURE

1. Allow the water to flow from the inlet or gate valve through the pipe to the convergent cone, then the level of the pyrometer rises to some height.
2. Measure the pressure head in the piezometer.
3. Allow the water to flow from the convergent to the throat and from the throat to the divergent cone
4. Hence level in the piezometer rises to some height. Rising depends upon the rate of flow of water.
5. Allow the water to flow into the collecting tank through the outlet and after filling some amount of water in the collecting tank the water level in the piezometer increases. Measure the time taken for every 10 cm rise in the piezometer.
6. Repeat the experiment 6 times by altering the discharge.

OBSERVATIONS

Plan area of the volumetric tank A = cm²

Table 1: Tabulation for C_d calculation[illegible]

AIM OF THE EXPERIMENT

Determination of coefficient of discharge for orifice meter by IS 15675:2006.

APPARATUS REQUIRED

1. A measuring tank of size $0.6 \times 0.6 \times 0.8$ metres with overflow arrangement and a drain valve.
2. Stopwatch.
3. Orifice meter fitted onto horizontal pipes of diameters 20 mm, 25 mm, and 40 mm with pressure tapping and gate valves to regulate the flow rate.
4. Differential mercury manometer with the wooden scale of 1m length and scale graduations of 1 mm to measure the loss of head.

THEORY

An orifice meter is an instrument that is generally used for measuring the rate of flow of a fluid through a pipe. It consists of a flat circular plate that has a circular sharp edge hole called an orifice which is concentric with the pipe. The orifice diameter is generally kept 0.5 times the diameter of the pipe. The general formula for the coefficient of discharge of the orifice meter is

$$Q = C_d \frac{A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}} \quad \dots(1)$$

where C_d = coefficient of discharge.

The coefficient of discharge for the orifice meter is much smaller than venturimeter.

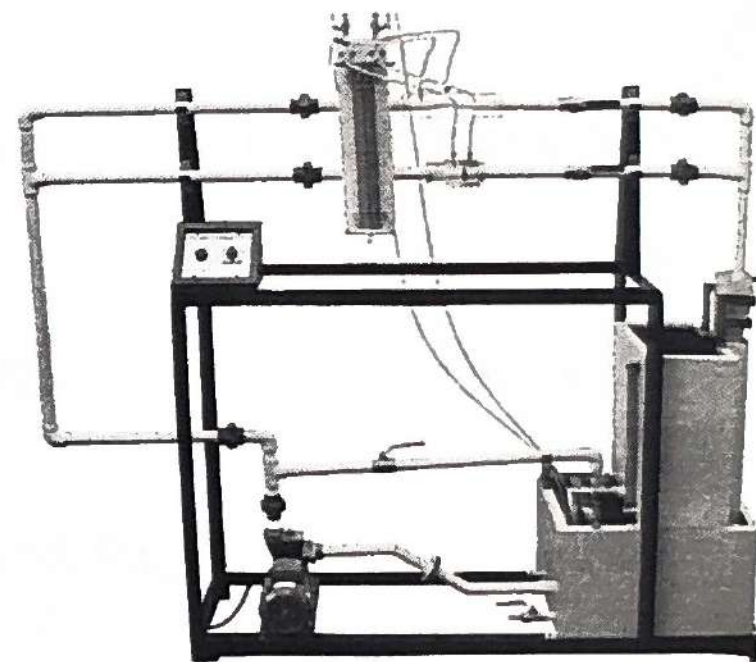


Fig. 1. Orifice Meter

PROCEDURE

1. Close the valves of the inlet pipe, orifice meter pipeline, and manometer.
2. The gate valve of the pipeline selected for the experimentation is opened.
3. The needle valves of the corresponding manometer and orifice meter are opened.
4. Adjust the control valve kept at the exit side of the orifice to the desired flow rate and maintain the flow.
5. Note down the readings of the manometer and time for 10 cm rise in measuring tank.

OBSERVATION AND CALCULATION

Diameter of orifice meter =

Area of cross-section =

Area of collecting tank =

Sr. No.	Pipe diameter (mm)	Orifice diameter (mm)
1.	20	13.41
2.	25	16.77
3.	40	26.83

Table 2: Coefficient of discharge

Sl. No.	Manometer Reading mm of	Time is taken for a 10cm rise	Q_{th} (m ³ /s)	Q_{act} (m ³ /s)	C_d	Avg C_d

RESULT

The coefficient of discharge is

POSSIBLE QUESTIONS

- Why is coefficient of discharge less for the orifice meter than for venturi meter?**
Ans. Because of the sudden contraction at the orifice and the subsequent sudden expansion after the orifice, the coefficient of discharge C_d for the orifice meter is much lower than that of a venturi meter or a flow nozzle.
- Why is a venturi meter more accurate than an orifice meter?**
Ans. Venturimeter is based on the integral form of Euler's equation. Venturimeter is based on Bernoulli's equation. Orifice meter can only be used for measuring the rate of flow in the open pipe-like structure.
- What is the basic principle of the orifice meter?**
Ans. Basic working principle of an orifice meter is based on the liquid or gas whose flow rate is to be determined and is passed through the orifice plate. This creates a pressure drop across the orifice plate which varies with the flow rate, resulting in differential pressure between the outlet and inlet segments.
- How does an orifice meter measure flow?**
Ans. Orifice plates are a primary flow element, detecting the flow of fluid passing through the plate by sensing the pressure drop across the plate. When a fluid flows through a restriction in a pipe, it creates a pressure difference between upstream and downstream of the restriction.
- What is beta ratio in the orifice meter?**
Ans. The ratio of orifice bore diameter (d) to the pipe inside diameter (D) is called the beta ratio (β). $\beta = d/D$. The orifice plate has a typical bore diameter that ranges from 30% to 75% of the inside diameter of the pipework in which it is installed.
- Why is the coefficient of discharge less than 1?**
Ans. The reason why C_d values are always less than 1 is that the actual discharge will always be less than the theoretical discharge idealized by Torricelli. This is so due to the effect of surface tension and friction from the external fluid.
- What is the flow discharge coefficient?**
Ans. In a nozzle or other constriction, the discharge coefficient (also known as the coefficient of discharge or efflux coefficient) is the ratio of the actual discharge to the ideal discharge.

AIM OF THE EXPERIMENT

To determine the coefficient of discharge for a given type notch (triangular, rectangular).

APPARATUS REQUIRED

1. Different shaped notches
2. Hook gauge
3. Stopwatch
4. Collecting tank with a piezometer

THEORY

Notches are overflow structures where the length of crest along the flow of water is accurately shaped to calculate discharge. A notch may be defined as a sharp-edged obstruction over which the flow of a liquid occurs. The sheet of water discharged by a notch is called a vein. Notches are used for measuring the flow of water from a reservoir and are generally rectangular, trapezoidal, or triangular in shape. The most common shape is triangular since it has the advantage of greater accuracy at reduced flow rates compared with other shapes. The coefficient of contraction will be constant for all heads. A triangular notch is called a V notch. The value of C_d with different heads will be nearly constant. The value of C_d varies from 0.59 to 0.62 depending upon the dimensions of the notch. The rectangular weir (notch) is a common device used to regulate and measure discharge in irrigation projects.

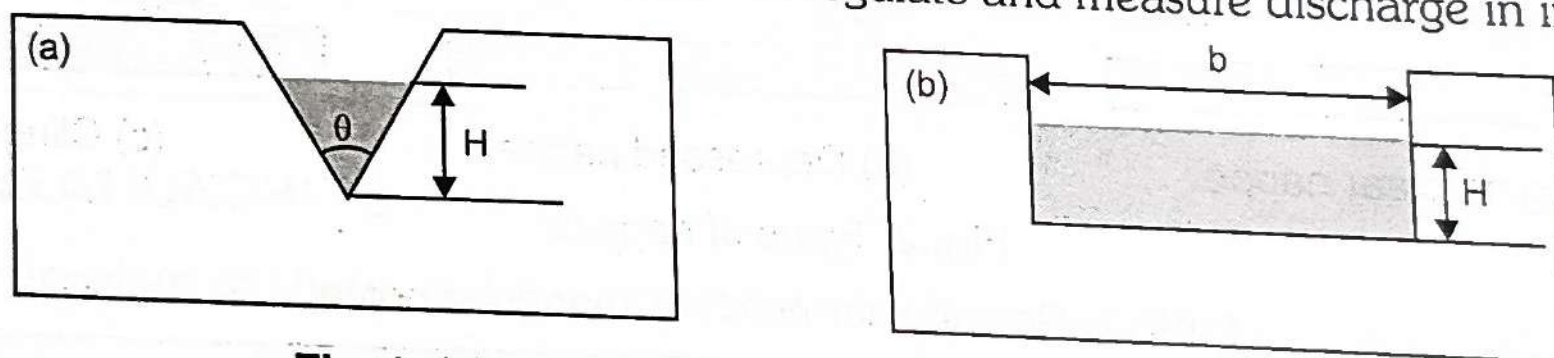


Fig. 1. (a) Triangular notch, (b) Rectangular notch

For a triangular notch, the theoretical discharge is

$$Q = C_d \frac{8}{15} \sqrt{2g} \tan \frac{\theta}{2} H^{\frac{5}{2}} \quad \dots(1)$$

For a Rectangular notch, the theoretical discharge is

$$Q = C_d \frac{2}{3} \sqrt{2gb} H^{\frac{3}{2}} \quad \dots(2)$$

For a triangular notch $C_d = \frac{15Q}{8\sqrt{2g} \tan \left(\frac{\theta}{2} \right) H^{\frac{5}{2}}} \quad \dots(3)$

For a rectangular notch $C_d = \frac{3Q}{2bH^{\frac{3}{2}} \sqrt{2g}} \quad \dots(4)$

Where,

Q is flow rate

H is height above the weir base

b is width of rectangular weir (R-notch)

θ is the angle of triangular weir (V-notch)

C_d is discharge coefficient to account for the effects of simplifying assumptions in the which must be determined by experiment.

PROCEDURE

- The notch under test is positioned at the end of the tank with a vertical sharp edge on the upstream
- Open the inlet valve and fill water until the crest of the notch.
- Note down the height of crest level by pointer gauge.
- Change the inlet supply and note the height of this level in the tank.
- Note the volume of water collected in the collecting tank for a particular time and find out the discharge
- Height and discharge readings for different flow rates are noted.

OBSERVATIONS

Use the following tables to record your measurements. Record any observations of the shape and the nappe, paying particular attention to whether the nappe was clinging or sprung clear, and of the end contraction and general change in shape. (See Figure 2 to classify the nappe).

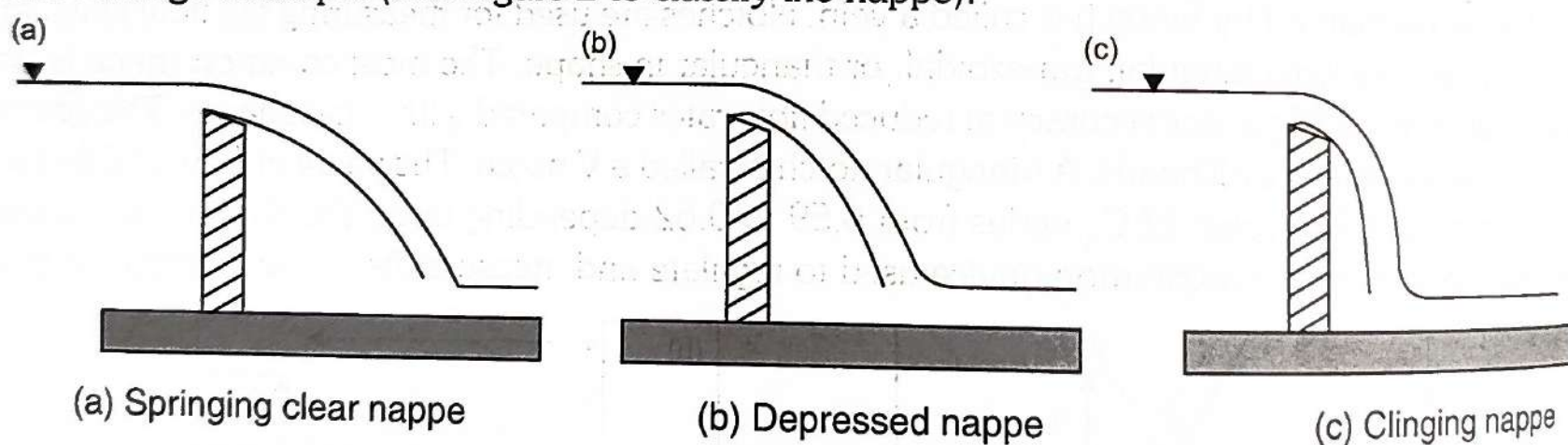


Fig. 2. Types of nappes

Table 1. Rectangular-notch or Triangular notch

Test no.	Datum height h_0 (m)	Water surface elev. h (m)	Volume collected (L)	Time for collection (s)
1				
2				
3				
4				
5				

CALCULATIONS

The following dimensions from the equipment can be used in the appropriate calculations:

- width of rectangular notch (b) = _____ m
- the angle of V-notch (θ) = _____ °

Calculate the discharge (Q) and head (h) for each experiment and record them in the Results Tables. For calculation purposes, the depth of the water above the weir is the difference between each water level reading and the datum reading, i.e., $H = h - h_0$

Calculate $H^{5/2}$ and $H^{3/2}$ for the triangular and rectangular notches, respectively.

For each measurement, calculate the experimental values for the triangular and rectangular notches, using Equations 3 and 4, respectively.

Record your calculations in the Results Tables.

Table 2. Rectangular notch

No.	H (m)	Volume collected (m^3)	Flow rate (m^3/s)	$H^{3/2}$	Experimental C^d	Theoretical C^d	% Error

Table 3. Triangular notch

No.	H (m)	Volume collected (m^3)	Flow rate (m^3/s)	$H^{5/2}$	Experimental C^d	Theoretical C^d	% Error

GRAPHICAL RELATIONSHIPS

- Schematic drawings or photos of the nappes observed during each experiment, with an indication of their type.
- Plot a graph of Q (y-axis) against $H^{3/2}$ (x-axis) for the rectangular weir and Q against $H^{5/2}$ for the triangular weir. Use a linear function to plot the best fit and express the relationship between Q and H^n in the form of $Q = mH^n$ in which the exponent value n is 1.5 for the rectangular weir and 2.5 for the triangular weir. Calculate the coefficients of discharge C^d (theoretical method) using Equations 5 and 6. Record C^d values calculated from the theoretical method in the Results Tables.
- Compare the experimental results to the theory by calculating the percentage of error.

POSSIBLE QUESTIONS

Why is a triangular notch preferable to a rectangular notch?

ns. A triangular notch or weir is preferred to a rectangular weir or notch because the expression for discharge for a right-angled V-notch or weir is very simple. For measuring the low discharge, a triangular notch gives more accurate results than a rectangular notch.

Is the coefficient of discharge a constant for all notches?

ns. The coefficient of discharge for the two notches is different due to the height of the water level.