FLUID MECHANICS AND MACHINERY LABORATORY

STUDENTS REFERENCE MANUAL

DEPARTMENT OF MECHANICAL ENGINEERING

AWH ENGINEERING COLLEGE KOZHIKODE

FLUID MECHANICS AND MACHINERY LABORATORY

GENERAL INSTRUCTIONS TO STUDENTS

- The purpose of this laboratory is to reinforce and enhance your understanding of the fundamentals of Fluid mechanics and Hydraulic machines. The experiments here are designed to demonstrate the applications of the basic fluid mechanics principles and to provide a more intuitive and physical understanding of the theory. The main objective is to introduce a variety of classical experimental and diagnostic techniques, and the principles behind these techniques. This laboratory exercise also provides practice in making engineering judgments, estimates and assessing the reliability of your measurements, skills which are very important in all engineering disciplines.

- Read the lab manual and any background material needed before you come to the lab. You must be prepared for your experiments before coming to the lab. In many cases you may have to go back to your fluid mechanics textbooks to review the principles dealt with in the experiment.

- Please actively participate in class and don't hesitate to ask questions. Please utilize the teaching assistants fully. To encourage you to be prepared and to read the lab manual before coming to the laboratory, unannounced questions may be asked at any time during the lab.

- Never carry out unauthorized experiments. Come to the laboratory prepared. If you are unsure about what to do, please ask the instructor.

- Carelessness in personal conduct or in handling equipment may result in serious injury to the individual or the equipment. Do not run near moving machinery. Always be on the alert for strange sounds. Guard against entangling clothes in moving parts of machinery.

- Students must follow the proper dress code inside the laboratory. To protect clothing from dirt, wear a lab coat. Long hair should be tied back. Shoes covering the whole foot will have to be worn.

- Don't forget to bring calculator, graph sheets and drawing accessories when you come to lab.

- In performing the experiments, please proceed carefully to minimize any water spills, especially on the electric circuits and wire.

- Make your workplace clean before leaving the laboratory. Maintain silence, order and discipline inside the lab.

- Don't use cell phones inside the laboratory.

- Any injury no matter how small, must be reported to the instructor immediately.

- Start writing your Laboratory records early, don't wait till the day before the lab records are due. Most experiments require a significant amount of analysis, which cannot be done properly if you start one or two days before the due date. Start early and give yourself time to get help in case you run into problems, we can not help you if you wait till the last moment.

- Wish you a nice experience in this lab!

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EXPERIMENT 1

VERIFICATION OF BERNOULLI'S THEOREM

1.1 Objectives

The objective is to validate Bernoulli's assumptions and theorem by experimentally proving that the sum of the terms in the Bernoulli equation along a streamline always remains a constant.

1.2 Equipment required

Apparatus for the verification of Bernoulli's theorem and measuring tank with stop watch setup for measuring the actual flow rate.

1.3 Principle

The Bernoulli theorem is an approximate relation between pressure, velocity, and elevation, and is valid in regions of steady, incompressible flow where net frictional forces are negligible. Despite its simplicity, it has been proven to be a very powerful tool for fluid mechanics. The key approximation in the derivation of Bernoulli's equation is that viscous effects are negligibly small compared to inertial, gravitational, and pressure effects. We can write the theorem as,

$$\text{Pressure head } \left(\frac{P}{\rho g}\right) + \text{ Velocity head } \left(\frac{V^2}{2g}\right) + \text{ Elevation } (Z) = \text{a constant} \quad (1.1)$$

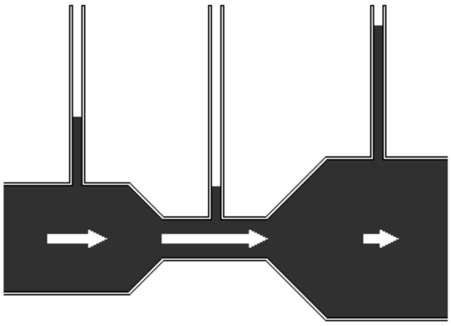


Figure 1.1: Pressure head increases with decrease in velocity head.

where, P = the pressure.(N/m^2)

ρ = density of the fluid, kg/m^3

V = velocity of flow, (m/s)

g = acceleration due to gravity, m/s^2

Z = elevation from datum line, (m)

Note that all the individual terms in the summation have the same dimension, *m* of fluid.

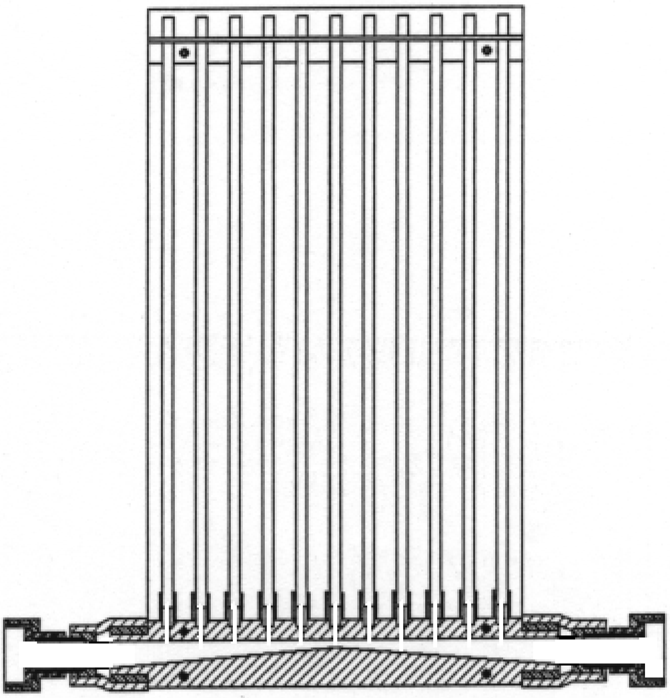


Figure 1.2: Apparatus.

The discharge through the test section can be determined using the collecting tank and stopwatch setup.

$$\text{Actual discharge, } Q_{ac} = \frac{a \times H}{t} \quad (m^3/s) \tag{1.2}$$

where, a = area of the collecting tank.(m^2)

H = height difference of the water column in the piezometer, (m)

t = time taken to rise H meters, (sec)

The velocity of flow at the cross section A_1 is, $V_1 = \frac{Q_ac}{A_1}$. Then the velocity head , $H_{v1} = \frac{V_1^2}{2g}$. Assuming that the pipe line has negligible frictional losses in the flow and the elevation is constant everywhere, Bernoulli's's equation for the horizontal pipe at cross section A_1 can be verified as, Pressure head (H_{P1}) + Velocity head (H_{v1}) = Const:

1.4 Procedure

1. Observe the dimensions of the convergent divergent duct of the apparatus. Note it down. Measure the collecting tank cross sectional area.
2. Open the inlet valve to the supply tank and allow water to fill up to a high level.
3. Open the outlet valve and regulate both the inlet and outlet valves so that the head in the supply tank remains constant.
4. Note the time to collect water for a specific rise in the collecting tank and thus find the discharge through the duct.
5. Note down the all the piezometer readings at different locations A_1, A_2, ..up-to A_{11}.
6. Repeat the experiment for a medium and low head levels in the supply tank.
7. Plot the curves showing the variation of H_p, H_v and H_t with position and tabulate the readings.

1.5 Observations and calculations

Collecting tank size = — cm^2

No	Head, H	Time for collecting V m^3 of water in tank	Duct No.	Area, A	Velocity	Velocity Head, $H_v=v^2/2g$	Pressure Head, H_p
	cm	sec		cm^2	cm/s	cm	cm
1	High		1				
			2				
			..				
			..				
			11				
2	Medium		1				
			2				
			..				
			..				
			11				
3	Low		1				
			2				
			..				
			..				
			11				

1.6 Results and Inference

The Bernoulli’s theorem is verified and the variation in total head is due to frictional losses.

EXPERIMENT 2

CALIBRATION OF OBSTRUCTION FLOW METERS

2.1 Objectives

The aim of this experiment is to 1. Calibrate the given obstruction flowmeters, 2. Plot the characteristics and to find their coefficient of discharge for different rates of flow and 3. Obtain an appreciation of how these meters work and of the theory behind the apparatus.

2.2 Equipment required

Supply pipe connected with the flow meters, a differential manometer to measure the pressure difference across the the obstruction and a collecting tank with stop watch to measure the actual rate of flow.

2.3 Principle

The obstruction flow meter is a device used to measure the discharge of an internal flow. In these meters flow rate is calculated by measuring the pressure drop over an obstruction which is inserted in to path of the flow. There are many classifications according to the type obstruction used. The most commonly used categories are Venturi meter, orifice meter and nozzle meter.

Venturi meters are generally made from castings machined to close tolerances to duplicate the performance of the standard design, so they are heavy,

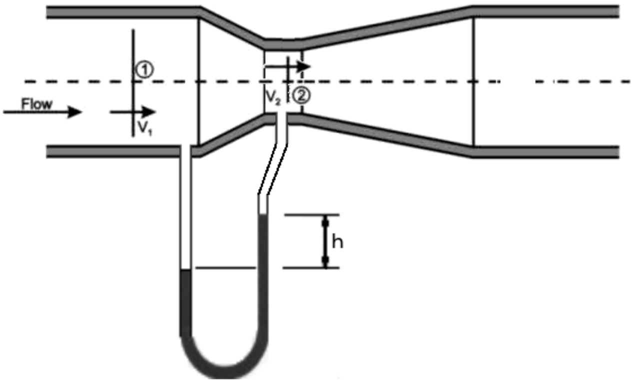


Figure 2.1: Venturi meter

bulky, and expensive. Inside the venturi meter the fluid is accelerated through a converging cone of angle $15 - 20^o$. The pressure difference between the upstream side of the cone and the throat is measured by using a differential manometer and it provides a measure for the discharge. The conical diffuser section downstream from the throat with a lower angle $8 - 12^o$ gives excellent pressure recovery and so overall head loss is low compared to other obstruction flow meters. Venturi meters are self-cleaning because of their smooth internal shape.

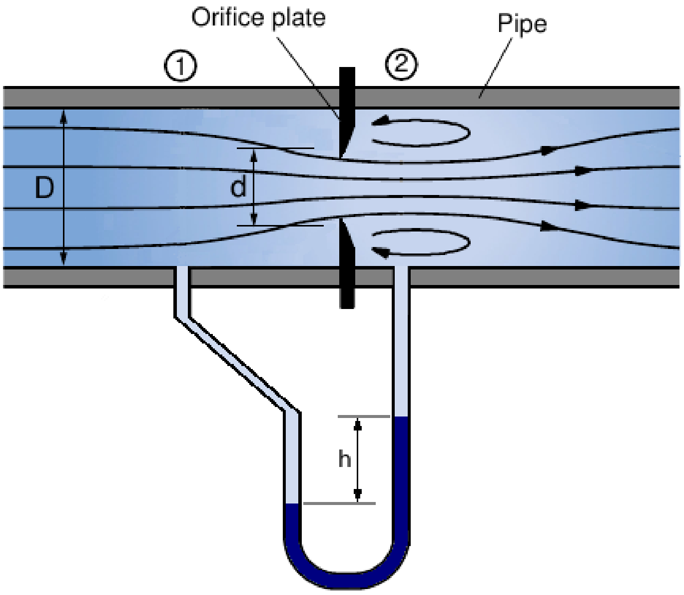


Figure 2.2: Orifice meter

The orifice meter consists of a flat orifice plate with a circular hole drilled in it. The construction is very simple and so cost is low compared to other obstruction meters. There is a pressure tap upstream from the orifice plate and another just downstream. Reduction of cross-section of the flowing stream in passing through orifice increases the velocity head at the expense of pressure head. This reduction of pressure between taps is measured using a differential manometer and it gives a measure of the discharge. The pressure recovery is poor compared to the Venturi meter.

The expression for discharge through any obstruction flow meter can be theoretically obtained using the continuity and Bernoulli's equations together. The Bernoulli's equation is defined for steady, incompressible and inviscid regions of flow. Since the Bernoulli's equation is a simplified form of energy equation, the assumptions used for simplification must be satisfied when using it for practical cases. The continuity equation for discharge (Q) through a pipe with the above assumptions is,

$$Q_{th} = A\ V, \text{ where A= flow area } (m^2) \text{ and V=flow velocity } (m/s) \tag{2.1}$$

Let the pipe area be A_1 and the throat area of the meter be A_2. Then we can write the continuity equation as,

$$Q_{th} = A_1 V_1 = A_2 V_2 = \text{a const.}$$

$$\text{which implies,} V_1 = \left(\frac{A_2}{A_1}\right) V_2$$

Now the Bernoulli's equation is stated as,

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

Since $Z_1 = Z_2$, we can substitute V_1 from the continuity equation and rearrange to get,

$$V_2 = \sqrt{\frac{2\ \Delta P}{\rho_w \left(1 - \left(\frac{A_2}{A_1}\right)^2\right)}}$$

where,$\Delta P = P_1 - P_2$ is the pressure drop between the inlet and the throat of the meter in N/m^2. Since we use Mercury differential manometers to measure ΔP we can use the relation $\Delta P = (\rho_{Hg} - \rho_w) gh$ for conversion, where h is the height of mercury column.

So the theoretical expression for discharge becomes,

$$Q_{th} = A_1 A_2 \sqrt{\frac{2 \times \left(\frac{\rho_{Hg}}{\rho_w} - 1\right) gh}{(A_1^2 - A_2^2)}} \tag{2.2}$$

where, g = acceleration due to gravity (m/s^2)

ρ_{Hg} = density of the manometer fluid, (kg/m^3)

ρ_W = density of the flowing fluid, (kg/m^3)

Actual discharge through the device can be determined using the collecting tank and stopwatch setup.

$$\text{Actual discharge,}\ \ Q_{ac} = \frac{a \times H}{t}\ \ (m^3/s) \tag{2.3}$$

where, a = area of the collecting tank, (m^2)

H= height difference of the water column in the piezometer, (m)

t = time taken to rise H meters, (sec)

The coefficient of discharge C_D, is defined as the ratio of actual discharge obtained experimentally to the theoretical discharge obtained using the expression we derived. i.e.,

$$C_D = \frac{Q_{ac}}{Q_{th}} \tag{2.4}$$

The next step is the calibration of the meters. Calibration process is the validation of specific measurement techniques and equipment. It is the comparison between measurements of known magnitude made with one device and another measurement made in as similar way as possible with a second device. In order to use any device for measurement it is necessary to empirically calibrate them. That is, here in the case of flow meter, pass a known discharge through the meter and note the reading in order to provide a standard for measuring other quantities in a different location. Provided the standard mechanics of construction are followed no further calibration is required for a similar second device with same geometry.

In general, the calibration equation for flow meters is stated as,

$$Q_{ac} = K \times h^n. \tag{2.5}$$

where K and n are constants depending on the geometry of the obstruction flow meter. Taking logarithm on both sides we get,

$$\log Q_{ac} = \log k + n \log h \tag{2.6}$$

which is the equation of a straight line, where $\log k$ is the y intercept and n is its slope. The experimental values obtained are used to find the values of k and n. The graph $\log Q_{ac}$ Vs. $\log h$ is to be plotted to find them.

2.4 Procedure

1. Check the experimental setup for leaks. Measure the dimensions of collecting tank. Note down the flow meter specifications.
2. Open the inlet valve fully and allow the water to fill fully in the flow meter.
3. Make sure the height of Mercury column in both limbs are same if there is no discharge through the meter.
4. Slightly open the outlet valve of the flow meter and observe the manometer limbs.
5. Adjust it to get a steady pressure difference between the limbs of the manometer. Note down the corresponding Mercury levels.
6. Measure the time t to collect H height of water in the collecting tank.
7. Repeat the above procedure for different flow rates by changing the outlet valve opening. Tabulate the readings.
8. Change the pressure tapping valves and repeat the same procedure for second meter.
9. Close the inlet to the apparatus after taking the necessary readings.
10. Complete the tabulation and find the average value of C_D in both cases.
11. Draw the necessary graphs and calibrate the meters.

2.5 Observations and calculations

Diameter of the throat = —m

Diameter of the pipe = —m

Collecting tank area = — m^2

No	Manometer Reading			Actual Discharge Q_{ac}	Time for L cm rise in Collecting Tank	Theoretical discharge Q_{th}	Coeff: of Discharge C_D	$\log_e (Q_{ac})$	$\log_e (h)$	$Q_{cal} = K \times h^n$
	h_1	h_2	Net H							
	cm	cm	m	m^3/s	sec	m^3/s				m^3/s
Venturi Meter	1									
	2									
	..									
	..									
	..									
	8									
Orifice Meter	1									
	2									
	..									
	..									
	..									
	8									

2.6 Results and Inference

The given flow meters are calibrated with the calibration equation $Q = K \times h^n$, where k=__, n=__ for venturi meter and k=__, n=__ for orifice meter.

The average coefficient of discharge of the given obstruction meters are,

Venturi meter, C_{DV} =

Orifice meter , C_{DO} =

The required characteristics are plotted.

EXPERIMENT 3

CALIBRATION OF EXTERNAL FLOW MEASURING NOTCHES

3.1 Objectives

The objectives of this experiment are 1. Determine the coefficient of discharge of the given external flow measuring notches for different rates of flow, 2. Plot the calibration graph, $log(Q_a)$ Vs. $log(H)$ and thus to calibrate the instrument by determining the constants K and n, assuming the actual discharge to be $Q_{ac} = Kh^n$, and 3. Plot the characteristics C_d Vs. h and Q_{ac} Vs. h and Q_{cal} Vs. h.

3.2 Equipment required

The given notch fitted on an open channel of the experiment setup, hook gauge to measure the water level over the notch and measuring tank with stop watch to measure the actual flow rate.

3.3 Principle

In open channel flows, weirs are commonly used to either regulate or to measure the volumetric flow rate. They are of particular use in large scale situations such as irrigation schemes, canals and rivers. For small scale applications, weirs are often referred to as notches and are sharp edged and manufactured from thin plate material. The basic principle is that discharge is directly related to the water depth above the crotch (bottom) of the notch. This distance is called head over the notch. Due to the minimal installation costs flow rate measurement with a notch is very less expensive.

The rectangular notch is the most commonly used thin plate weir. The V-notch or triangular notch design causes small changes in discharge to have a large change in depth allowing more accurate head measurement than with a rectangular notch.

The flow pattern over a notch or weir is complex and there is no analytical solution to the relationship between discharge and head so that a semi-empirical approach has to be used.

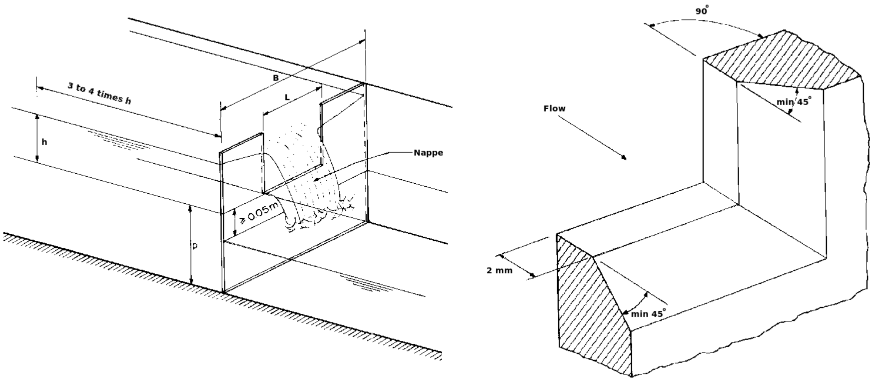


Figure 3.1: Rectangular notch.

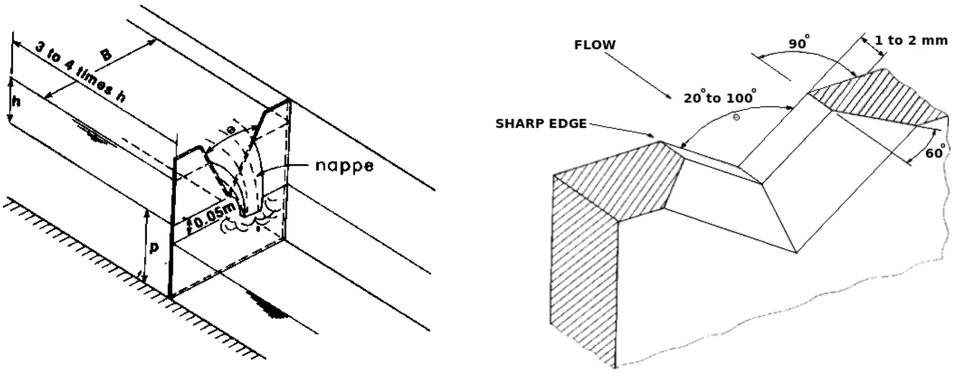


Figure 3.2: Triangular notch.

The expression for discharge over a rectangular notch is given by,

$$Q_{th} = \frac{2}{3}\sqrt{2g}\;\; L\, h^{3/2} \tag{3.1}$$

while, for triangular notch is,

$$Q_{th} = \frac{8}{15}\tan\left(\frac{\theta}{2}\right)\sqrt{2g}\;\; h^{5/2} \tag{3.2}$$

where, L = width of the notch, (m)

θ= angle of the notch, (deg)

h= head of water over the notch, (m)

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

Water is allowed to pass through the given notch at different flow rates. Actual discharge through the channel can be determined using the collecting tank and stopwatch setup.

$$\text{Actual discharge, } Q_{ac} = \frac{a \times H}{t} \quad (m^3/s) \tag{3.3}$$

where, a = area of the collecting tank.(m^2)
H = height difference of the water column in the piezometer, (m)
t = time taken to rise H meters, (sec)

The coefficient of discharge C_D is defined as the ratio of actual discharge obtained experimentally to the theoretical discharge. i.e.,

$$C_D = \frac{Q_{ac}}{Q_{th}} \tag{3.4}$$

Calibration is the validation of specific measurement techniques and equipment. It is the comparison between measurements of known magnitude made with one device and another measurement made in as similar way as possible with a second device. In order to use any device for measurement it is necessary to empirically calibrate them. That is, here in this case pass a known discharge through the notch and note the reading in order to provide a standard for measuring other quantities in a different location. Provided the standard mechanics of construction are followed no further calibration is required for a similar second device with same geometry.

The calibration equation is stated as,

$$Q_{ac} = K \times h^n. \tag{3.5}$$

where K and n are constants depending on the geometry of the notch. Taking logarithm on both sides we get,

$$\log Q_{ac} = \log k + n \log h \tag{3.6}$$

which is the equation of a straight line, where $\log k$ is the y intercept and n is its slope. The graph $\log Q_{ac}$ Vs. $\log h$ is to be plotted to find k and n.

3.4 Procedure

1. Check the experimental setup for leaks. Measure the dimensions of collecting tank and the notch.
2. Observe the initial reading of the hook gauge and make sure there is no discharge. Note down the sill level position of the hook gauge.
3. Open the inlet valve of the supply pipe for a slightly increased discharge. Wait for sometime till the flow become steady.
4. Adjust the hook gauge to touch the new water level and note down the reading. Difference of this hook gauge reading with initial still level reading is the head over the notch (h).
5. Collect the water in the collecting tank and observe the time t to collect H height of water.
6. Repeat the above procedure for different flow rates by adjusting the inlet valve opening and tabulate the readings.
7. Complete the tabulation and find the mean value of C_D.
8. Draw the necessary graphs and calibrate the the notch.

3.5 Observations and calculations

Length of the rectangular notch = —*m*

Angle of the triangular notch = —*deg*

Collecting tank area = — m^2

No	Hook gauge Readings			Actual Discharge Q_{ac}	Time for L cm rise in Collecting Tank	Theoretical discharge Q_{th}	Coeff: of Discharge C_D	$\log_e(Q_{ac})$	$\log_e(h)$	$Q_{cal} = K \times h^n$
	Sill Level h_1	h_2	Net h							
	cm	cm	m	m^3/s	sec	m^3/s				m^3/s
Rectangular Notch										
Triangular Notch										

3.6 Results and Inference

The given notches are calibrated with the calibration equation $Q = K \times h^n$, where k=__, n=__ for rectangular notch and k=__, n=__ for triangular notch.

The average coefficient of discharge of the given notches are,

$$\text{Rectangular notch, } C_{DR} =$$
$$\text{Triangular notch, } C_{DT} =$$

The required characteristics are plotted.

EXPERIMENT 4

FLOW COEFFICIENTS OF MOUTHPIECE AND ORIFICE

4.1 Objectives

The objective of this experiment is to find and study the variations of hydraulic coefficients under different operating conditions of the given orifice and mouthpiece.

4.2 Equipment required

Mouthpiece apparatus, orifice apparatus and measuring tanks with a stop watch for measuring the actual flow rate. The mouthpiece and orifice apparatus in the laboratory are slightly different. The orifice apparatus has an sliding hook gauge with it to measure the co-ordinates of the moving jet.

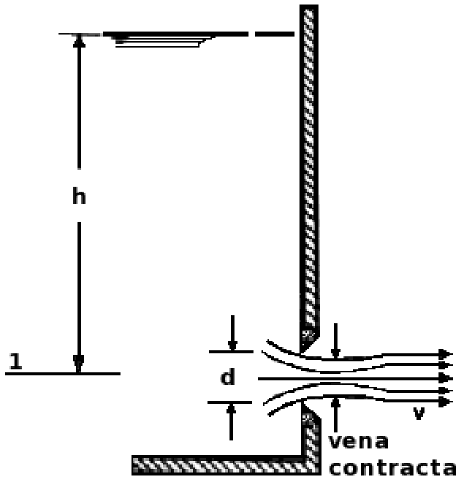


Figure 4.1: Orifice.

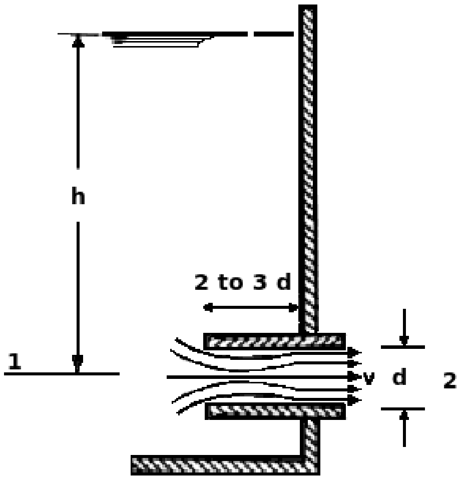


Figure 4.2: Mouthpiece.

4.3 Principle

Orifice is a flat sharp edged small circular hole fitted in one side of a reservoir containing fluid. They may be classified on the basis of their size, shape, upstream edge and the discharge conditions. Most commonly used are circular and rectangular orifices. A mouthpiece is a short pipe of length not more than two or three times its diameter, connected to an orifice of same size provided in the wall of a reservoir containing fluid. It is an extension of the orifice and through which the fluid is discharged. Both are used to determine the discharge through a tank. A cylindrical mouthpiece a length of, two or three times diameter, with its inner end-flush with the wall of the reservoir so as to form a sharp cornered entrance is called standard mouthpiece or Borda mouthpiece. A mouthpiece usually flows full, if it does not, then it acts like a notch.

The fluid emerges out through the orifice as a free jet to the atmosphere, and is acted upon by gravity. The thickness of the wall is assumed to be small compared to the diameter of the orifice. Because of the convergence of the streamlines approaching the orifice, the cross section of the jet decreases slightly until the pressure is equalized over the cross-section, and the velocity profile is nearly rectangular. This point of minimum area is called the *'vena contracta'*. Beyond the vena contracta, friction with the fluid outside the jet (air) slows it down, and the cross section increases. This divergence is usually quite small, and the jet is nearly cylindrical with a constant velocity. The jet is held together by surface tension. The ratio of the area of vena contracta to the orifice area is called the coefficient of contraction. In the case of a mouthpiece the vena contracta remains inside the pipe, and then the jet expands to fill the tube completely. Finally the jet emerging out of the mouthpiece will have the same diameter of the pipe. As the tube flows full at its outlet the coefficient of contraction is unity.

Neglecting frictional losses and applying Bernoulli's theorem to a point inside the reservoir and other at the exit of the orifice, both being at the level of the center line, we get,

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2 \tag{4.1}$$

where the subscript 1 and 2 are the properties at the regions shown in the figure and h is the height of water column in the reservoir. Now, canceling the zero terms on both sides we get,

$$\frac{\rho gh}{\rho g}+\frac{0}{2g}+0=\frac{0}{\rho g}+\frac{V^2}{2g}+0$$

$$\text{which implies } h=\frac{V^2}{2g} \text{ or } V_{th}=\sqrt{2gh}$$

Then, the theoretical discharge through the orifice will be,

$$Q_{th} = a_o \times V_{th} \tag{4.2}$$

The actual discharge is less than the theoretical discharge due to friction loss and the loss due to re-expansion of the jet. The actual discharge through the mouthpiece can be determined using the collecting tank and stopwatch setup.

$$\text{Actual discharge, } Q_{ac} = \frac{a \times H}{t} \quad (m^3/s) \tag{4.3}$$

where, a = area of the collecting tank.(m^2)

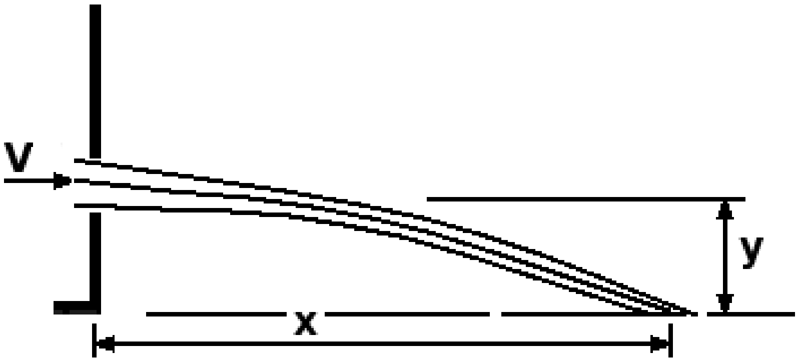
H = height difference of the water column in the piezometer, (m)

t = time taken to rise H meters, (sec)

The coefficient of discharge C_D is defined as the ratio of the actual discharge to theoretical discharge.

$$C_D = \frac{Q_{ac}}{Q_{th}} \tag{4.4}$$

The actual velocity of the jet through the orifice is found out by measuring the co-ordinates of the moving jet and applying Newton's laws. Refer figure below. The co-ordinates x and y of any point on the jet are measured using the sliding hook gauge.



We know,

$$S = ut + \frac{1}{2}at^2 \tag{4.5}$$

Using the above equation the vertical and horizontal displacements y and x can be expressed as,

$$x = Vt + 0 \quad \text{and}$$
$$y = 0 + \frac{1}{2}gt^2$$

Canceling t and solving for v, we get the expression for actual velocity of the jet emerging out from the orifice.

$$V_{ac} = \sqrt{\frac{gx^2}{2y}} \tag{4.6}$$

The coefficient of velocity C_V is defined as the ratio of actual velocity obtained experimentally to the theoretical velocity obtained using the expression we derived. i.e.,

$$C_V = \frac{V_{ac}}{V_{th}} \tag{4.7}$$

The coefficient of contraction C_C is defined as the ratio of area of vena contracta of the jet to the actual area of the orifice. It is found theoretically from the following equation.

$$C_D = \frac{Q_{ac}}{Q_{th}} = C_C \times C_V$$

In the case of mouthpiece the actual velocity of the jet at the exit is found out using the continuity equation,

$$Q_{ac} = a_m \times V_{ac} \tag{4.8}$$

4.4 Procedure

1. Note the dimensions of the discharge measuring tank, orifice and the mouthpiece.
2. Check that the zero of the scale of the inlet tank is the same level as the center line of the mouthpiece or orifice. If not, measure the difference in elevation and take it as zero error.
3. Adjust the opening of the inlet valve till the water level in the supply tank become steady.

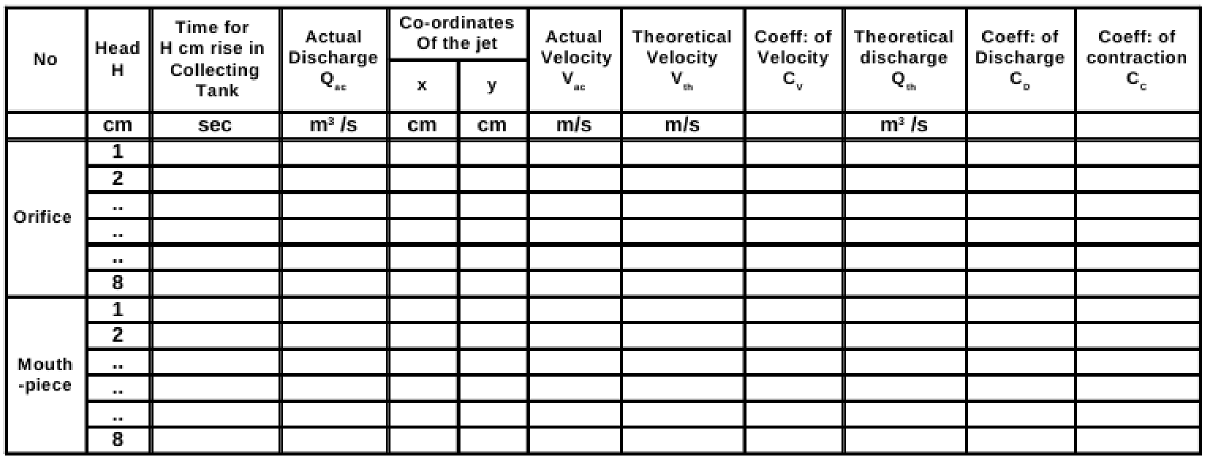
4. Note down the head.
5. Using the hook gauge arrangement measure the co-ordinates of the jet in a convenient point.
6. Using collecting tank and stop watch setup measure the actual discharge.
7. Repeat the experiment for different inlet valve openings and tabulate the readings.
8. Plot the characteristics C_D Vs h, C_C Vs h and C_V Vs h.

4.5 Observations and calculations

Collecting tank size = — m^2

Diameter of the orifice =— m

Diameter of the mouthupiece =— m



No	Head H	Time for H cm rise in Collecting Tank	Actual Discharge Q_{ac}	Co-ordinates Of the jet		Actual Velocity V_{ac}	Theoretical Velocity V_{th}	Coeff: of Velocity C_V	Theoretical discharge Q_{th}	Coeff: of Discharge C_D	Coeff: of contraction C_C
				x	y						
	cm	sec	m^3/s	cm	cm	m/s	m/s		m^3/s		
Orifice	1										
	2										
	..										
	..										
	..										
	8										
Mouth -piece	1										
	2										
	..										
	..										
	..										
	8										

4.6 Results and Inference

Hydraulic coefficients, C_D =

C_v =

EXPERIMENT 5

FRICTIONAL LOSSES IN PIPE FLOW

5.1 Objectives

The goal of this experiment is to study pressure losses due to frictional effects (major losses) in fluid flow through pipes.

5.2 Equipment required

The pipe flow rig with pipes of different materials, a collecting tank with stop watch to measure the discharge and a differential manometer to measure the pressure drop in the test section.

5.3 Principle

When a fluid flows through a pipe, there is a loss of energy (or pressure) in the fluid. This is because energy is dissipated to overcome the viscous (frictional) forces exerted by the walls of the pipe as well as the moving fluid layers itself. In addition to the energy lost due to frictional forces, the flow also loses pressure as it goes through fittings, such as valves, elbows, contractions and expansions. The pressure loss in pipe flows is commonly referred to as head loss. The frictional losses are referred to as major losses while losses through fittings etc, are called minor losses. Together they make up the total head losses.

The Reynolds number Re is a dimensionless number that gives a measure of the ratio of inertial forces ($V\rho$) to viscous forces (μ/L). It is a very useful quantity and aids in classifying fluid flows.

$$Re = \frac{\rho V L_c}{\mu} \tag{5.1}$$

where, ρ = density of the fluid, (kg/m^3) .

V = average velocity of flow inside the pipe, (m/s).

L_c= characteristic dimension = D for pipe flows, (m).

μ = dynamic viscosity of the fluid, $(Pa \cdot s)$.

For flow through a pipe experimental observations show that laminar flow occurs when $Re < 2300$ and turbulent flow occurs when $Re > 4000$. In the between 2300 and 4000, the flow is termed as transition flow where both laminar and turbulent flows are possible.

The average velocity of flow can be found out by measuring the actual discharge using the collecting tank and stop watch. Then the average flow velocity will be,

$$V = \frac{\text{discharge}}{\text{area of the pipe}} \tag{5.2}$$

The head loss due to friction in pipe flows can be calculated using the *Darcy-Weisbach* equation. It is a phenomenological equation, which relates the head loss due to friction along a given length of pipe to the average velocity of the fluid flow.

$$h_f = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} \tag{5.3}$$

where, h_f = head loss due to friction, (m of fluid).

V = average velocity of flow inside the pipe, (m/s).

L/D= length to diameter ratio of the pipe, (m).

f = a dimensionless coefficient called the *Darcy friction factor*.

The Darcy friction factor f is not a constant and depends on the parameters of the pipe and the velocity of the fluid flow. It may be evaluated for given conditions by the use of various empirical or theoretical relations, or it may be obtained from Moody diagrams. The Darcy friction factor for laminar flow $(Re < 2300)$ is given by the following formula:

$$f = \frac{64}{\text{Re}} \tag{5.4}$$

The value of the Darcy friction factor may be subject to large uncertainties in the transition flow regime and so here the equation for turbulent flow is assumed to be valid. For turbulent flow *Colebrook equation* has to be used to find f.

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right) \tag{5.5}$$

Which is an implicit equation and is difficult to solve. An approximate explicit form, called the *Haaland equation* is commonly used.

$$\frac{1}{\sqrt{f}} = -1.8\log_{10}\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11} + \frac{6.9}{Re}\right] \tag{5.6}$$

where, ε/D is the relative roughness of the pipe.

5.4 Procedure

1. Measure and record the relevant dimensions required.
2. Observe the inverted U-tube manometer. Make sure the level of water is same in both limbs.
3. Open the desired pressure tap valve from the pipe line to the manometer. Make sure only one is open at a particular time.
4. Open the inlet gate valve and adjust the flow using the outlet gate valve.
5. Note the manometer readings.
6. Measure the discharge through the pipe using collecting tank and stop watch.
7. Repeat the procedure for different flow rates and for different pipes.
8. Tabulate the readings. Draw the plot showing the variation of f with Reynolds number.

5.5 Observations and Calculations

Collecting tank area, a $=$—m^2

Diameter of pipes, D $=$—m

Length of test section, L $=$—m

NO.		Manometer readings		Pressure drop	Discharge		Average velocity of flow	Reynolds number, Re	Flow Regime	Friction factor, [f_{exp}]	Friction factor, [f_{the}]	% deviation
		h_1	h_2		Time for collecting H m water	Q						
		cm water	cm water	m water	sec	m^3/s	m/s					%
Pipe 1	1											
	2											
	3											
	4											
Pipe 2	1											
	2											
	3											
	4											
Pipe 3	1											
	2											
	3											
	4											

5.6 Results and Inference

The Darcy friction factor for the three different pipes for different values of Reynolds number have been found out experimentally and compared with the theoretical results.

EXPERIMENT 6

CONSTANT SPEED CHARACTERISTICS OF SINGLE STAGE CENTRIFUGAL PUMP

6.1 Objectives

To find the performance characteristics of a centrifugal pump and to find its specific speed.

6.2 Equipment required

Centrifugal pump test rig, energy meter to measure the input electrical energy, pressure gauges at the suction and delivery sides, a collecting tank-stopwatch setup to measure the discharge.

6.3 Principle

A centrifugal pump is a rotodynamic pump that uses a rotating impeller to increase the pressure of a fluid. It works by the conversion of the rotational kinetic energy, typically from an electric motor to an increased static fluid pressure. They are commonly used to move liquids through a piping system. In pump terminology, the rotating assembly that consists of the shaft, the hub, the impeller blades and the shroud is called the impeller. Centrifugal pumps are used for large discharge through smaller heads.

Fluid enters axially through the hollow middle portion of the pump called the eye, after which it encounters the rotating blades. It acquires tangential and radial velocity by momentum transfer with the impeller blades, and acquires additional radial velocity by centrifugal forces. The flow leaves the impeller after gaining both speed and pressure as it is flung radially outward into the scroll (or volute). The purpose of the scroll is to decelerate the fast-moving fluid leaving the trailing edges of the impeller blades, thereby further increasing the fluid pressure, and to combine and direct the flow from all the blade passages toward a common outlet. If the flow is steady, incompressible and if the outlet and inlet diameters are are same, then, according to the continuity equation the average flow speed at the outlet is identical to that at the inlet.

The performance of a pump is characterized by its net head h, which is defined as the change in Bernoulli head between the suction side and the delivery side of the pump. h is expressed in equivalent column height of water.

$$h_w = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{delivery} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{suction} \tag{6.1}$$

The subscripts stands for suction or delivery sides. This equation can also be written as,

$$\text{Net head, } h_w = \frac{(P_{del} - P_{suc})}{\rho g} + \frac{(V_{del}^2 - V_{suc}^2)}{2g} + (Z_{del} - Z_{suc}) \tag{6.2}$$

where, P = Absolute water pressure, (N/m^2)

V = Velocity of water inside the pipe, (m/s)

ρ = Density of the water, (kg/m^3)

g = acceleration due to gravity, (m/s^2)

Z = elevation, (m).

The velocity of water can be calculated using discharge and diameter of the pipes. The discharge produced by the pump can be determined using the collecting tank and stopwatch setup.

$$\text{Discharge, } Q = \frac{a \times H}{t} \quad (m^3/s) \tag{6.3}$$

where, a = area of the collecting tank.(m^2)

H = height difference of the water column in the piezometer, (m)

t = time taken to rise H meters, (sec)

The net head is proportional to the useful power actually delivered to the fluid in the pump. Traditionally it is called the water horsepower(whp), even if the power is not measured in horsepower. It is defined as,

$$P_{whp} = \rho Q \times g h_w \quad (Watts) \tag{6.4}$$

The input electrical energy to the motor can be determined using the watt hour energy meter. The expression for power is,

$$E_{in} = \frac{3600 \times n \times 1000}{k \times t} \qquad (Watts) \tag{6.5}$$

where, n = number of revolutions of the energy meter disk.

k = energy meter constant, $rev/kWhr$.

t = time taken for n revolutions, (sec)

In pump terminology the external energy supplied to the pump is called the brake horsepower(bhp) of the pump, which can be calculated by considering the efficiency of the motor.

$$p_{bhp} = \eta_{motor} \times E_{in}$$

The pump efficiency η_{pump} is defined as the ratio of useful power to supplied power,

$$\eta_{pump} = \frac{P_{bhp}}{P_{whp}} \tag{6.6}$$

The specific speed N_{sp} of a pump is defined as,

$$N_{sp} = \frac{\omega\sqrt{Q}}{(gh_w)^{3/4}} \tag{6.7}$$

where, ω = Angular velocity of the motor shaft, (rad/sec)

h_w = Net head of the pump, (m of water)

The specific speed will be a constant for a particular pump, or pumps similar to it. If we know the head, speed and the discharge desired, it is easy to find the general type of rotodynamic pump that would prove satisfactory using specific speed. But it is not really a speed, and is a dimensionless number. The speed and discharge used in the expression should be the speed and discharge for maximum efficiency. Centrifugal pumps have low specific speeds among rotodynamic pumps, ranging from 0.02 to 1.5.

6.4 Procedure

1. Check the pressure gauges. Make sure both of them show atmospheric pressure.

2. Observe the suction and delivery pipe diameters. Measure the dimensions of collecting tank. Measure the difference in elevation between the suction and delivery pressure tappings.
3. Prime the centrifugal pump. Keep the delivery valve fully closed.
4. Start the pump.
5. Open the delivery valve slightly. Observe the pressure gauge readings.
6. Measure the discharge using the collecting tank stopwatch setup.
7. Note the time for n revolutions of the energy meter disk.
8. Open the delivery valve gradually to maximum. Repeat the above observations for different discharges.
9. Tabulate the readings. Draw the performance characteristics; H Vs. Q, P_{bhp} Vs. Q and η Vs. Q.

6.5 Observations and Calculations

Collecting tank area, a =

Diameter of suction pipe, D_{suc} =

Diameter of delivery pipe, D_{del} =

Speed of the motor, N =

Energy meter constant, k =

Elevation difference, $Z_{del} - Z_{suc}$ =

Sl. No.	Discharge		Suction pressure	Delivery pressure	Velocity of flow		Velocity head	Datum Head $Z_1 - Z_2$	Net head H_{net}	Water horse power P_{whp}	Brake horse power P_{bhp}	Pump Efficiency
	Time for collecting H m water	Q			Suction	Delivery						
	sec	m^3/s	Kg/cm^2	- mm Hg	m/s	m/s	m	m	m	W	W	%

6.6 Results and Inference

1. The average pump efficiency, $\eta_{pump,avg}=$
2. The maximum pump efficiency, $\eta_{pump,max}=$
3. The specific speed of the given centrifugal pump, $N_{sp}=$

EXPERIMENT 7

VARIABLE SPEED CHARACTERISTICS OF SINGLE STAGE CENTRIFUGAL PUMP

7.1 Objectives

To find the variable speed characteristics of a single stage centrifugal pump and to find its specific speed.

7.2 Equipment required

Single stage variable speed centrifugal pump test rig, discharge pipe fitted with a venturi meter, electrical systems to vary the motor speed, voltmeter and ammeter to find the amount of electrical energy input to the pump, tachometer to find the speed of pump etc.

7.3 Principle

A centrifugal pump is a rotodynamic pump that uses a rotating impeller to increase the pressure of a fluid. It works by the conversion of the rotational kinetic energy, typically from an electric motor to an increased static fluid pressure. They are commonly used to move liquids through a piping system. In pump terminology, the rotating assembly that consists of the shaft, the hub, the impeller blades and the shroud is called the impeller.

The performance of a pump is characterized by its net head h, which is defined as the change in Bernoulli head between the suction side and the delivery side of the pump. h is expressed in equivalent column height of water.

$$h_w = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{delivery} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_{suction} \tag{7.1}$$

The subscripts stands for suction or delivery sides. This equation can also be written as,

$$\text{Net head, } h_w = \frac{(P_{del} - P_{suc})}{\rho g} + \frac{(V_{del}^2 - V_{suc}^2)}{2g} + (Z_{del} - Z_{suc}) \tag{7.2}$$

where, P = Absolute water pressure, (N/m^2)

V = Velocity of water inside the pipe, (m/s)

ρ = Density of the water, (kg/m^3)

g = acceleration due to gravity, (m/s^2)

Z = elevation, (m).

The velocity of water can be calculated using discharge and diameter of the pipes. The discharge produced by the pump can be determined using the venturi meter provided in the delivery pipe.

$$\text{Discharge, } Q = kH^n \quad (m^3/s) \tag{7.3}$$

where, k, n = calibration constants of the venturi meter

H = height difference of the mercury column in manometer, (m)

The net head is proportional to the useful power actually delivered to the fluid in the pump. Traditionally it is called the water horsepower(whp), even if the power is not measured in horsepower. It is defined as,

$$P_{whp} = \rho Q \times g h_w \quad (Watts) \tag{7.4}$$

The input electrical energy to the motor can be determined using the watt hour energy meter. The expression for power is,

$$E_{in} = \frac{3600 \times n \times 1000}{k \times t} \quad (Watts) \tag{7.5}$$

where, n = number of revolutions of the energy meter disk.

k = energy meter constant, $(rev/kWhr)$.

t = time taken for n revolutions, (sec)

In pump terminology the external energy supplied to the pump is called the brake horsepower(bhp) of the pump, which can be calculated by considering the efficiency of the motor.

$$p_{bhp} = \eta_{motor} \times E_{in}$$

The pump efficiency η_{pump} is defined as the ratio of useful power to supplied power,

$$\eta_{pump} = \frac{P_{bhp}}{P_{whp}} \tag{7.6}$$

The specific speed N_{sp} of a pump is defined as,

$$N_{sp} = \frac{\omega\sqrt{Q}}{(gh_w)^{3/4}} \tag{7.7}$$

where, ω = Angular velocity of the motor shaft, (rad/sec)

h_w = Net head of the pump, (m of water)

The specific speed will be a constant for a particular pump, or pumps similar to it. If we know the head, speed and the discharge desired, it is easy to find the general type of rotodynamic pump that would prove satisfactory using specific speed. But it is not really a speed, and is a dimensionless number. The speed and discharge used in the expression should be the speed and discharge for maximum efficiency. Centrifugal pumps have low specific speeds among rotodynamic pumps, ranging from 0.02 to 1.5.

7.4 Procedure

1. Check the pressure gauges. Make sure both of them show atmospheric pressure.
2. Observe the suction and delivery pipe diameters. Measure the dimensions of collecting tank. Measure the difference in elevation between the suction and delivery pressure tappings.
3. Prime the centrifugal pump. Keep the delivery valve fully closed.
4. Start the pump.
5. Open the delivery valve slightly. Observe the pressure gauge readings.
6. Measure the discharge using the collecting tank stopwatch setup.
7. Note the time for n revolutions of the energy meter disk.
8. Open the delivery valve gradually to maximum. Repeat the above observations for different discharges.
9. Tabulate the readings. Draw the performance characteristics; H Vs. Q, P_{bhp} Vs. Q and η Vs. Q.

7.5 Observations and Calculations

Collecting tank area, a =

Diameter of suction pipe, D_{suc} =

Diameter of delivery pipe, D_{del} =

Speed of the motor, N =

Energy meter constant, k =

Elevation difference, $Z_{del} - Z_{suc}$ =

Sl. No.	Discharge		Suction pressure	Delivery pressure	Velocity of flow		Datum head		Net head h_{net}	water horse power P_{whp}	Brake horse power P_{bhp}	Pump Efficiency
	Manometric head, h	$Q=kh^n$			Suction	Delivery	Z_1	Z_2				
	cm(Hg)	m^3/s	Kg/cm^2	- mm Hg	m/s	m/s	m	m	m	W	W	%

7.6 Results and Inference

1. The average pump efficiency, $\eta_{pump,avg}$ =
2. The maximum pump efficiency, $\eta_{pump,max}$ =
3. The specific speed of the given centrifugal pump, N_{sp} =

EXPERIMENT 8

PERFORMANCE OF RECIPROCATING PUMP

8.1 Objectives

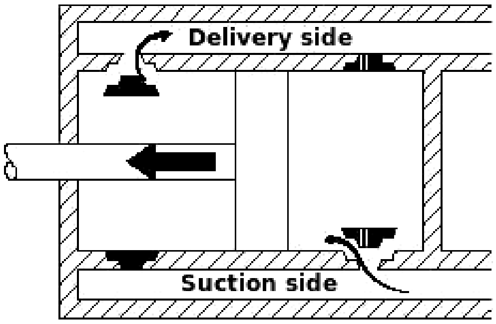
The objective is to study the performance characteristics of a reciprocating pump and to find the slip.

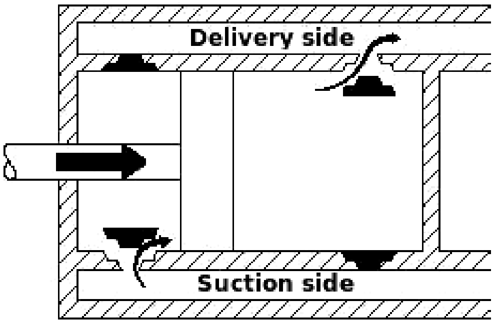
8.2 Equipment required

Reciprocating pump test rig, pressure gauges at the suction and delivery pipes, energy meter to measure the input electrical energy, a collecting tank stop watch setup to measure the discharge.

8.3 Principle

Reciprocating pump is a positive displacement pump, which causes a fluid to move by trapping a fixed amount of it then displacing that trapped volume into the discharge pipe. The fluid enters a pumping chamber via an inlet valve and is pushed out via a outlet valve by the action of the piston or diaphragm. They are either single acting; independent suction and discharge strokes or double acting; suction and discharge in both directions.





Reciprocating pumps are self priming and are suitable for very high heads at low flows. They deliver reliable discharge flows and is often used for metering duties because of constancy of flow rate. The flow rate is changed only by adjusting the rpm of the driver. These pumps deliver a highly pulsed flow. If a smooth flow is required then the discharge flow system has to include additional features such as accumulators. An automatic relief valve set at a safe pressure is used on the discharge side of all positive displacement pumps.

The performance of a pump is characterized by its net head h, which is defined as the change in Bernoulli head between the suction side and the delivery side of the pump. h is expressed in equivalent column height of water.

$$\text{Net head, } h_w = \frac{(P_{del} - P_{suc})}{\rho g} + \frac{(V_{del}^2 - V_{suc}^2)}{2g} + (Z_{del} - Z_{suc}) \tag{8.1}$$

The subscripts stands for suction or delivery sides.

where, P = Absolute water pressure, (N/m^2)
V = Velocity of water inside the pipe, (m/s)
ρ = Density of the water, (kg/m^3)
g = acceleration due to gravity, (m/s^2)
Z = elevation, (m).

The velocity of water can be calculated using discharge and area of the pipes. The discharge produced by the pump can be determined using the collecting tank and stopwatch setup.

$$\text{Discharge, } Q = \frac{a \times H}{t} \quad (m^3/s) \tag{8.2}$$

where, a = area of the collecting tank.(m^2).
H = height difference of the water column in the piezometer, (m).
t = time taken to rise H meters, (sec).

The net head is proportional to the useful power actually delivered to the fluid in the pump. Traditionally it is called the water horsepower(whp), even if the power is not measured in horsepower. It is defined as,

$$P_{whp} = \rho Q \times g h_w \quad (Watts) \tag{8.3}$$

The input electrical energy to the motor can be determined using the watt hour energy meter. The expression for power is,

$$E_{in} = \frac{3600 \times n \times 1000}{k \times t} \qquad (Watts) \tag{8.4}$$

where, n = number of revolutions of the energy meter disk.

k = energy meter constant, $rev/kWhr$.

t = time taken for n revolutions, (sec)

In pump terminology the external energy supplied to the pump is called the brake horsepower(bhp) of the pump, which can be calculated by considering the efficiency of the motor.

$$p_{bhp} = \eta_{motor} \times E_{in}$$

The pump efficiency η_{pump} is defined as the ratio of useful power to supplied power,

$$\eta_{pump} = \frac{P_{bhp}}{P_{whp}} \tag{8.5}$$

The theoretical discharge of a reciprocating pump can be calculated by knowing the geometrical specifications and and rate of travel of the piston, since it is positive displacement type. The volume of the fluid displaced will be equal to the stoke volume of the piston inside the cylinder. For a double acting single cylinder reciprocating pump the displaced volume of water per second is given by,

$$Q_{th} = \frac{LNA}{60} + \frac{LN(A - A_{pr})}{60} \qquad (m^3/s) \tag{8.6}$$

where, L = Stroke length of piston, (m).

N = Rotating speed of the pump crankshaft, (rpm).

A = Area of the piston, (m^2).

A_{pr} = Area of the piston rod, (m^2).

The slip of a reciprocating pump is defined as,

$$\text{Slip} = \frac{Q_{th} - Q_{ac}}{Q_{th}} \tag{8.7}$$

8.4 Procedure

1. Check the pressure gauges. Make sure both of them show atmospheric pressure.
2. Observe the suction and delivery pipe diameters. Measure the dimensions of collecting tank. Measure the difference in elevation between the suction and delivery pressure tappings.

3. Open the delivery valve fully. Never close this valve below a critical level to reduce the flow rate. The fluid has no place to go and something will break.
4. Start the pump.
5. Note down the pressure gauge readings.
6. Measure the discharge using the collecting tank stopwatch setup.
7. Note the time for n revolutions of the energy meter disk.
8. Close the delivery valve gradually. Repeat the above observations for different discharges.
9. Tabulate the readings. Draw the performance characteristics; H Vs. Q, P_{bhp} Vs. Q and η Vs. Q.

8.5 Observations and Calculations

Sl. No.	Discharge		Suction pressure	Delivery pressure	Velocity of flow		Velocity head	Datum Head Z_1 -Z_2	Net head H_{net}	Water horse power P_{whp}	Brake horse power P_{bhp}	Pump Efficiency	Slip
	Time for collecting H m water	Q			Suction	Delivery							
	sec	m^3 /s	Kg/cm^2	- mm Hg	m/s	m/s	m	m	m	W	W	%	%

Collecting tank area, a =

Diameter of suction pipe, D_{suc} =

Diameter of delivery pipe, D_{del} =

Energy meter constant, k =

Elevation difference, $Z_{del} - Z_{suc}$ =

8.6 Results and Inference

1. The average pump efficiency is found to be, $\eta_{pump,avg}$=
2. The average slip of the given reciprocating pump, S_{avg}=

EXPERIMENT 9

PERFORMANCE OF GEAR PUMP

9.1 Objectives

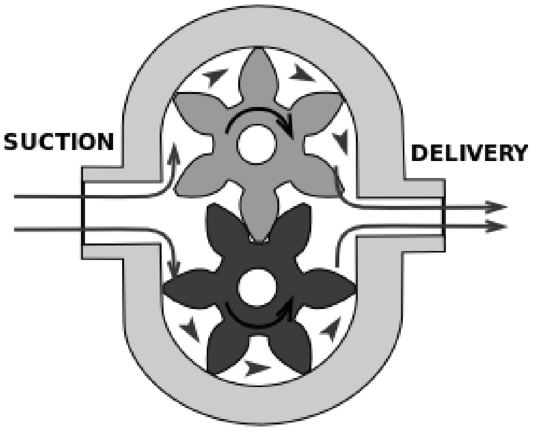
To investigate the performance of a gear pump and to plot the characteristics.

9.2 Equipment required

Gear pump test rig, storage tank with oil, pressure gauges at the suction and delivery pipes, energy meter to measure the input electrical energy, a collecting tank stop watch setup to measure the discharge.

9.3 Principle

Gear pump is a positive displacement pump which utilizes the meshing of two gears to pressurize the fluid. They are one of the most common types of pumps for hydraulic fluid power applications and are also widely used to pump highly viscous fluids.



As the gears rotate they separate on the intake side of the pump, creating a void and suction which is filled by fluid. The fluid is carried by the gears to the discharge side of the pump, where the meshing of the gears displace the fluid. The mechanical clearances are on the order of micrometers. The tight clearances, along with the speed of rotation, effectively prevent the fluid from leaking backwards. The rigid design of the gears and housing allow for very high pressures and the ability to pump highly viscous fluids.

The performance of any pump is characterized by its net head h, which is defined as the change in Bernoulli head between the suction side and the delivery side of the pump. h is expressed in equivalent column height of fluid which is pumped.

$$\text{Net head, } h_{oil} = \frac{(P_{del} - P_{suc})}{\rho g} + \frac{(V_{del}^2 - V_{suc}^2)}{2g} + (Z_{del} - Z_{suc}) \tag{9.1}$$

The subscripts stands for suction or delivery sides.

where, P = Absolute fluid pressure, (N/m^2)
V = Velocity of fluid inside the pipe, (m/s)
ρ = Density of the pumping fluid, (kg/m^3)
g = acceleration due to gravity, (m/s^2)
Z = elevation, (m).

The velocity of water can be calculated using discharge and area of the pipes. The discharge produced by the pump can be determined using the collecting tank and stopwatch setup.

$$\text{Discharge, } Q = \frac{a \times H}{t} \quad (m^3/s) \tag{9.2}$$

where, a = area of the collecting tank.(m^2).
H = height difference of the liquid column in the piezometer, (m).
t = time taken to rise H meters, (sec).

The net head is proportional to the useful power actually delivered to the fluid in the pump. Traditionally it is called the water horsepower(whp), even if the power is not measured in horsepower and the pumping fluid is not water. It is defined as,

$$P_{whp} = \rho Q \times g h_{oil} \quad (Watts) \tag{9.3}$$

The input electrical energy to the motor can be determined using the watt hour energy meter. The expression for power is,

$$E_{in} = \frac{3600 \times n \times 1000}{k \times t} \quad (Watts) \tag{9.4}$$

where, n = number of revolutions of the energy meter disk.

k = energy meter constant, $rev/kWhr$.

t = time taken for n revolutions, (sec)

In pump terminology the external energy supplied to the pump is called the brake horsepower(bhp) of the pump, which can be calculated by considering the efficiency of the motor.

$$p_{bhp} = \eta_{motor} \times E_{in}$$

The pump efficiency η_{pump} is defined as the ratio of useful power to supplied power,

$$\eta_{pump} = \frac{P_{bhp}}{P_{whp}} \tag{9.5}$$

9.4 Procedure

1. Check the pressure gauges. Make sure both of them show atmospheric pressure.
2. Observe the suction and delivery pipe diameters. Measure the dimensions of collecting tank. Measure the difference in elevation between the suction and delivery pressure tappings.
3. Open the delivery valve fully. Never close this valve below a critical level to reduce the flow rate. The fluid has no place to go and something will break.
4. Start the pump.
5. Note down the pressure gauge readings.
6. Measure the discharge using the collecting tank stopwatch setup.
7. Note the time for n revolutions of the energy meter disk.
8. Close the delivery valve gradually. Repeat the above observations for different discharges.
9. Tabulate the readings. Draw the performance characteristics; Q Vs. P_{whp}, P_{whp} Vs. P_{in} and η Vs. h.

9.5 Observations and Calculations

Collecting tank area, a =

Diameter of suction pipe, D_{suc} =

Diameter of delivery pipe, D_{del} =

Energy meter constant, k =

Elevation difference, $Z_{del} - Z_{suc}$ =

Sl. No.	Discharge		Suction pressure	Delivery pressure	Velocity of flow		Velocity head	Datum Head Z_1 - Z_2	Net head H_{net}	Water horse power P_{whp}	Brake horse power P_{bhp}	Pump Efficiency
	Time for collecting H m oil	Q			Suction	Delivery						
	sec	m^3 /s	Kg/cm^2	- mm Hg	m/s	m/s	m	m	m	W	W	%

9.6 Results and Inference

1. The average pump efficiency , $\eta_{pump,avg}$ =
2. The maximum pump efficiency e, $\eta_{pump,max}$ =

EXPERIMENT 10

LOAD TEST ON PELTON TURBINE

10.1 Objectives

To investigate the performance of the Pelton turbine with different range of flow rates and to find its specific speed.

10.2 Equipment required

Experimental setup consists of Pelton turbine, inlet pressure gauge, centrifugal pump, tachometer, pre-calibrated venturi meter with differential mercury manometer, brake drum dynamometer with rope and mass loading arrangement.

10.3 Principle

An impulse turbine is a turbomachine in which kinetic energy from one or more fast-moving jets is converted to rotational mechanical energy delivered to the shaft of the machine. A nozzle transforms water under a high head into a powerful jet. The momentum of this jet is destroyed by striking the runner, which absorbs the resulting force. No pressure change occurs at the turbine blades, and so the turbine doesn't require a housing for operation. The conduit bringing high-pressure water to the impulse wheel is called the pen-stock.

Impulse turbines are most often used in very high head applications. Several types of impulse turbines have been invented, but only one has survived in appreciable numbers to the present day, which is the Pelton turbine. The free water jet strikes the turbine buckets tangentially. Each bucket has a high center ridge so that the flow is divided to leave the runner at both sides. Pelton wheels are suitable for high heads, typically above about 450 meters with relatively low water flow rates. For maximum efficiency the runner tip speed should equal about one-half the striking jet velocity. The efficiency can exceed 91 percent when operating at 60-80 percent of full load.

The input hydraulic power, P_{in} to the turbine is the initial kinetic energy of the flowing water jet.

$$P_{in} = \frac{1}{2}mV^2 = \rho Q \times gh \tag{10.1}$$

where, g = Acceleration due to gravity, (m/s^2)

m = Mass flow rate of water, (kg/s)

V = Velocity of jet at the nozzle exit, (m/s)

h = Head over the turbine, (m) of water

Q = Volume flow rate to the turbine, (m^3/s)

ρ = Density of the water, (kg/m^3)

The flow rate of water through the turbine can be measured using the venturi meter connected in the inlet pipe line. The venturi meter is pre-calibrated with $Q = kh^n$ and the values of k and n are known. h is the change in pressure in terms of m of water. For a mercury manometer the this conversion is carried out using the equation,

$$h_w = \left(\frac{\rho_{Hg}}{\rho_w} - 1\right) \times h_{hg} \tag{10.2}$$

where, h_w = ΔP in terms of height of water column, (m)

h_{Hg} = ΔP in terms of height of Mercury column, (m)

ρ_{Hg} = density of the manometer fluid, (kg/m^3)

ρ_w = density of the flowing fluid, (kg/m^3)

The shaft of the turbine runner is connected to a brake drum dynamometer with rope and mass loading arrangement to measure the output brake power.

$$P_{br} = \frac{2\pi NT}{60} = \frac{2\pi N \times L \times \frac{D_e}{2}}{60} = \frac{\pi D_e NL}{60} \tag{10.3}$$

where, P_{br} = output brake power of the turbine, $(Watts)$

T = Torque acting on the runner shaft, (Nm)

N = Rotating speed of turbine shaft, (rpm)

L = Effective load on the brake drum, (N)

D_e = Effective diameter of the brake drum, (m)

The effective load on the brake drum is calculated as,

$$L = (W_{hanger} + W_{added} - W_{Spring \quad balance}) \times g$$

where, g is the acceleration due to gravity, (m/s^2).

The turbine efficiency is defined as the ratio of the power available on the brake drum to the hydraulic power supplied to the turbine.

$$\eta_{tur} = \frac{P_{br}}{P_{in}} \tag{10.4}$$

The specific speed N_{st} of a water turbine is defined as,

$$N_{st} = \frac{\omega\sqrt{P_{br}}}{\rho_w^{1/2}(gh_w)^{5/4}} \tag{10.5}$$

where, P_{br} = output brake power of the turbine, $(Watts)$

ω = angular velocity of turbine shaft, (rad/sec)

The specific speed will be a constant for a particular turbine, or turbines similar to it. If we know the head, speed and power desired, it is easy to find the general type of turbine that would prove satisfactory using specific speed. But it is not really a speed, and is a dimensionless number. The speed and power used in the expression should be the speed and power for maximum efficiency. Impulse turbines have low specific speeds, ranging from 0.05 to 0.2.

10.4 Procedure

1. Check the dynamometer mechanism and the differential manometer limbs. Note down the diameter of the brake drum. Change the dynamometer to zero-load position.

2. Prime the centrifugal pump, which is used generates high pressure head in the pen stock.

3. Keep the spear valve and the inlet gate valve completely closed. Start the pump.

4. Slowly open the gate valve and adjust the spear valve. Observe the minimum opening position of the valves to start the turbine at no load. Note down the manometer and the pressure gauge readings.

5. Regulate the valves to reach the rated speed at rated head of the turbine. Check the rpm using tachometer. Note down the readings.

6. Load the turbine by putting weights on the loading hanger. Turn on the cooling water supply to the brake drum.

7. Regulate the speed to rated speed by adjusting the valves. Note down the readings of the manometer, pressure gauge and the spring balance. Repeat the procedure by increasing the weight on the hanger gradually up to the maximum load.
8. Tabulate the readings.
9. Remove the loads on the hanger and and close the gate valve slowly and stop the centrifugal pump.
10. Calculate the brake power, efficiency and specific speed.
11. Plot the characteristics; P_{in} Vs. P_{br}, η_{tur} Vs. P_{br}, P_{br} Vs. Q and η_{tur} Vs. Q.

10.5 Observations and Calculations

Weight of rope and hanger =

Diameter of brake drum =

Diameter of the rope =

Rated speed and rated power =

The maximum load on the hanger =

Sl. No.	Inlet pressure	Manomter readings			Discharge Q	Input power P_{in}	Load on brake drum			Output power P_{br}	Turbine Efficiency
		h_1	h_2	h			Spring balance	Wt. on hanger	Effective load, L		
	Kg/cm^2	cm(Hg)	cm(Hg)	m(water)	m^3 /s	W	kg	kg	N	W	%

10.6 Results and Inference

1. The average turbine efficiency of the given Pelton turbine, $\eta_{tur,avg}$ = __
2. The specific speed of the turbine, N_{st} =
3. The minimum discharge required to start the turbine = __

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