LAB MANUAL

Open Channel Flow Laboratory (CE-311)

B. Tech VI Sem

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CONTENTS

List of Experiments:

1 TO STUDY THE FORMATION OF HYDRAULIC JUMP

1.1 AIM:

To study the formation of hydraulic jump in a rectangular channel and to determine the characteristics of the jump.

1.2 THEORY:

Hydraulic jumps occur when a supercritical stream encounters a subcritical stream with sufficient depth. The supercritical stream abruptly rises to meet its alternate depth, resulting in significant disturbances such as large-scale eddies and a reverse flow roller. However, these disturbances cause the jump to fall short of reaching its alternate depth. Figure 1-1 below provides a schematic representation of a typical hydraulic jump in a horizontal channel.

Section 1 marks the beginning of the jump, where the incoming supercritical stream experiences a sudden increase in depth, forming the toe of the jump. The main part of the jump is characterized by a steep change in the water-surface elevation, accompanied by a reverse flow roller. This roller entrains a significant amount of air, giving the water surface a frothy, white, and choppy appearance. Although the hydraulic jump maintains a generally steady state, it typically oscillates around a mean position in the longitudinal direction, resulting in an uneven surface.

Section 2, located beyond the roller, features a relatively level water surface and is referred to as the end of the jump. The distance between Sections 1 and 2 is known as the length of the jump, denoted as L. The initial depth of the supercritical stream is represented by y1, while y2 denotes the final depth of the subcritical stream after the jump. It should be noted that y2 is smaller than the depth corresponding to y1. These two depths at the ends of the jump are referred to as sequent depths.

The hydraulic jump incurs significant energy loss between Sections 1 and 2 due to high turbulence and the shear action of the roller. Estimating the precise nature of this energy loss is challenging, making it impractical to apply the energy equation to Sections 1 and 2 in order to establish relationships between various flow parameters. In such cases, it is recommended to use the momentum equation with appropriate assumptions. The hydraulic jump serves as a prime example where a thoughtful application of the momentum equation can yield meaningful results.

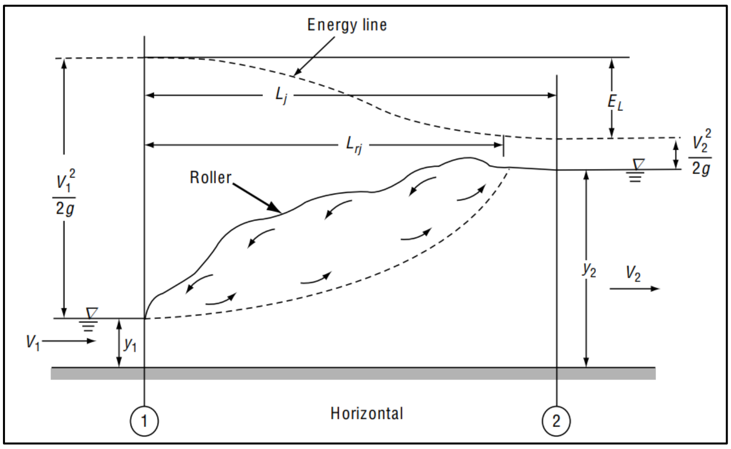


Figure 1-1: Schematic of Hydraulic Jump

1.3 GOVERNING EQUATIONS/FORMULAE FOR HYDRAULIC JUMP IN A HORIZONTAL RECTANGULAR CHANNEL

1.3.1 Sequent Depth Ratio

$$\frac{y_1}{y_2} = \frac{1}{2}\left(-1 + \sqrt{1 + 8F_1^{\ 2}}\right) \qquad \textbf{Equation 1-1}$$

$$F_1 = \frac{V_1}{\sqrt{gy_1}} \qquad \textbf{Equation 1-2}$$

1.3.2 Energy at section-1

$$E_1 = y_1 + \frac{q^2}{2gy_1^{\ 2}} \qquad \textbf{Equation 1-3}$$

1.3.3 Energy Loss

$$E_L = \frac{\left(y_2 - y_1\right)^3}{4y_1y_2} \qquad \textbf{Equation 1-4}$$

1.3.4 Energy Loss (Non-dimensional form)

$$\frac{E_L}{y_1} = \frac{1}{16}\frac{\left(-3 + \sqrt{1 + 8F_1^2}\right)^3}{\left(-1 + \sqrt{1 + 8F_1^2}\right)} \qquad \textbf{Equation 1-5}$$

1.3.5 Relative Energy Loss (Non-dimensional form)

$$\frac{E_L}{E_1} = \frac{1}{8\left(2 + F_1^2\right)}\frac{\left(-3 + \sqrt{1 + 8F_1^2}\right)^3}{\left(-1 + \sqrt{1 + 8F_1^2}\right)} \qquad \textbf{Equation 1-6}$$

1.3.6 Length of the Jump

$$L_i = 6.9\left(y_2 - y_1\right) \qquad \textbf{Equation 1-7}$$

1.3.7 Height of the Jump

$$h_i = y_2 - y_1 \qquad \textbf{Equation 1-8}$$

1.4 APPARATUS AND COMPONENTS REQUIRED:

a) Open channel flume

b) Stop watch

c) pointer gauge

d) Steel ruler

The set-up consists of a re-circulating rectangular tilting flow channel of dimensions (10m (l) × 0.3 m (b) m × 0.6 m (h). The upstream end of the channel is kept deep to dissipate the excess energy of flowing water. Two sluice gates are provided at up-stream and down-stream end of the flow channel to maintain regular flow. The flow channel is supported at one end on a jack for tilting and the other end is fixed on a MS powder coated frame. The MS frame has sump tank, measuring tank and centrifugal pump respectively. Water is supplied to the channel through centrifugal pump connected to a supply pipe. The centrifugal pump draws water form sump tank. Flow control valve and by-pass valve are provided in the supply pipe for regulating the flow in flume and determine discharge in measuring tank. Two perforated SS wave suppressors are used to dampen surface disturbances at the up-stream end of the channel. Hook and pointer gauges are provided to measure level of water in channel.

Figure 1-2: Glass walled Lab Flume

1.5 PROCEDURE:

1. Switch on the motor and open the delivery valve gradually. Ensure that no air gap in the motor pipe.
2. Adjust the delivery valve, sluice gate and the tailgate so that there forms a stable hydraulic jump in the flume.
3. Take the pointer gauge and measure bed level, water depths at the pre-jump section (1) and the post-jump section (2).
4. Measure discharge by collecting water in the collecting tank. Also, measure the length of jump, between sections (1) and (2).
5. Repeat steps (2) and (4) for other discharges by regulating the supply valve.
6. Repeat steps (2) and (5) for other positions of sluice gate and tail gate. Take at least 6 observations

1.6 OBSERVATIONS AND COMPUTATIONS:

Width of flume, **B =**

Run No.	Discharge measurement			Pre-jump depth, y_1	Post-jump depth, y_2
	Ay	t	q		
1					
2					
3					
..					
..					

Run No.	Discharge, q per unit width	y_2/y_1	F_1	F_2	E_L	h_i	L_i
1							
2							
3							
..							
..							
Average							

Make following plots on the graph paper and analyze the results.

- F_1 vs $\frac{y_1}{y_2}$
- F_1 vs $\frac{E_L}{y_1}$
- F_1 vs $\frac{E_L}{E_1}$

1.7 RESULTS:

Average height of the jump is:

Average length of the jump is:

Average energy loss of the jump is:

Observations from the graph:

1.8 QUESTIONS:

i.) What is the purpose of a hydraulic jump and what are its applications?

ii.) Derive the expression for the energy loss during a hydraulic jump also write down the assumption made.

iii.) Write short notes on followings.

a) Undulating jump,

b) Weak jump

c) Oscillating jump and

d) Strong jump

1.9 PRECAUTIONS:

- Make sure that the sluice gate is fitted properly, to form proper hydraulic jump.
- The hydraulic jump should be formed near the sluice gate.
- The flow should be varied and accordingly the tail gate should be changed

2 ENERGY LOSSES IN PIPES

2.1 INTRODUCTION

The total energy loss in a pipe system is the sum of the major and minor losses. Major losses are associated with frictional energy loss that is caused by the viscous effects of the fluid and roughness of the pipe wall. Major losses create a pressure drop along the pipe since the pressure must work to overcome the frictional resistance. The Darcy-Weisbach equation is the most widely accepted formula for determining the energy loss in pipe flow. In this equation, the friction factor (f), a dimensionless quantity, is used to describe the friction loss in a pipe. In laminar flows, f is only a function of the Reynolds number and is independent of the surface roughness of the pipe. In fully turbulent flows, f depends on both the Reynolds number and relative roughness of the pipe wall. In engineering problems, f is determined by using the Moody diagram.

2.2 PRACTICAL APPLICATION

In engineering applications, it is important to increase pipe productivity, i.e. maximizing the flow rate capacity and minimizing head loss per unit length. According to the Darcy-Weisbach equation, for a given flow rate, the head loss decreases with the inverse fifth power of the pipe diameter. Doubling the diameter of a pipe results in the head loss decreasing by a factor of 32 (≈ 97% reduction), while the amount of material required per unit length of the pipe and its installation cost nearly doubles. This means that energy consumption, to overcome the frictional resistance in a pipe conveying a certain flow rate, can be significantly reduced at a relatively small capital cost.

2.3 OBJECTIVE

The objective of this experiment is to investigate head loss due to friction in a pipe, and to determine the associated friction factor under a range of flow rates and flow regimes, i.e., laminar, transitional, and turbulent.

2.4 METHOD

The friction factor is determined by measuring the pressure head difference between two fixed points in a straight pipe with a circular cross section for steady flows.

2.5 EQUIPMENT

The following equipment is required to perform the energy loss in pipes experiment:

- Hydraulics bench,
- Pipe friction apparatus,
- Stopwatch for timing the flow measurement,
- Measuring cylinder for measuring very low flow rates,
- Spirit level, and
- Thermometer.

2.6 EQUIPMENT DESCRIPTION

The pipe friction apparatus consists of a test pipe (mounted vertically on the rig), a constant head tank, a flow control valve, an air-bleed valve, and two sets of manometers to measure the head losses in the pipe (Figure 2-1). A set of two water-over-mercury manometers is used to measure large pressure differentials, and two water manometers are used to measure small pressure differentials. When not in use, the manometers may be isolated, using Hoffman clamps.

Since mercury is considered a hazardous substance, it cannot be used in undergraduate fluid mechanics labs. Therefore, for this experiment, the water-over-mercury manometers are replaced with a differential pressure gauge to directly measure large pressure differentials.

This experiment is performed under two flow conditions: high flow rates and low flow rates. For high flow rate experiments, the inlet pipe is connected directly to the bench water supply. For low flow rate experiments, the inlet to the constant head tank is connected to the bench supply, and the outlet at the base of the head tank is connected to the top of the test pipe.

The apparatus' flow control valve is used to regulate flow through the test pipe. This valve should face the volumetric tank, and a short length of flexible tube should be attached to it, to prevent splashing.

The air-bleed valve facilitates purging the system and adjusting the water level in the water manometers to a convenient level, by allowing air to enter them.

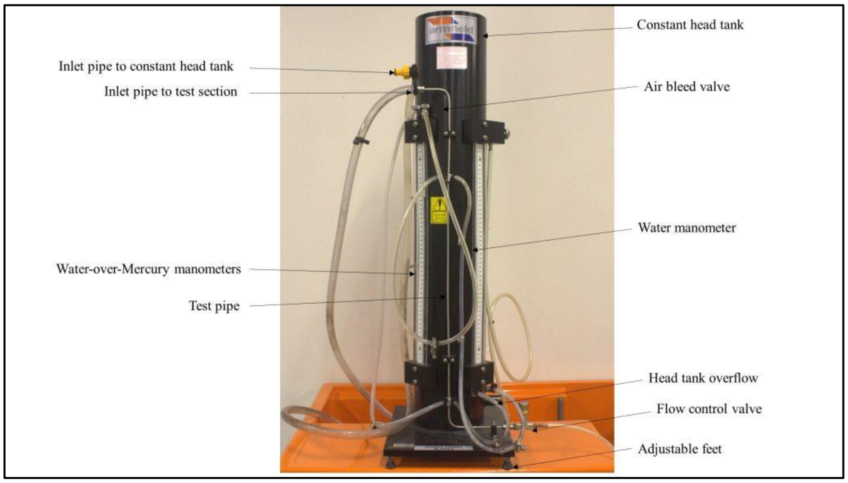


Figure 2-1: Pipe Friction Apparatus

2.7 THEORY

The energy loss in a pipe can be determined by applying the energy equation to a section of a straight pipe with a uniform cross section:

$$\frac{P_{in}}{\gamma} + \frac{v_{in}^2}{2g} + z_{in} = \frac{P_{out}}{\gamma} + \frac{v_{out}^2}{2g} + z_{out} + h_L \qquad \textbf{Equation 2-1}$$

If the pipe is horizontal: If the pipe is horizontal: $z_{in} = z_{out}$

Since: $v_{in} = v_{out}$

$$h_L = \frac{(P_{out} - P_{in})}{\gamma} \qquad \textbf{Equation 2-2}$$

The pressure difference ($P_{out} - P_{in}$) between two points in the pipe is due to the frictional resistance, and the head loss h_L is directly proportional to the pressure difference.

The head loss due to friction can be calculated from the Darcy-Weisbach equation:

$$h_L = f \frac{L}{D} \frac{v^2}{2g} \qquad \textbf{Equation 2-3}$$

where:
h_L : head loss due to flow resistance
f: Darcy-Weisbach coefficient
L: pipe length
D: pipe diameter
v: average velocity
g: gravitational acceleration.

For laminar flow, the Darcy-Weisbach coefficient (or friction factor *f*) is only a function of the Reynolds number (Re) and is independent of the surface roughness of the pipe, i.e.:

$$f = \frac{64}{Re}$$ **Equation 2-4**

For turbulent flow, f is a function of both the Reynolds number and the pipe roughness height, ϵ. Other factors, such as roughness spacing and shape, may also affect the value of *f*; however, these effects are not well understood and may be negligible in many cases. Therefore, f must be determined experimentally. The Moody diagram relates *f* to the pipe wall relative roughness, ϵ / D and the Reynolds number (Figure 2-2).

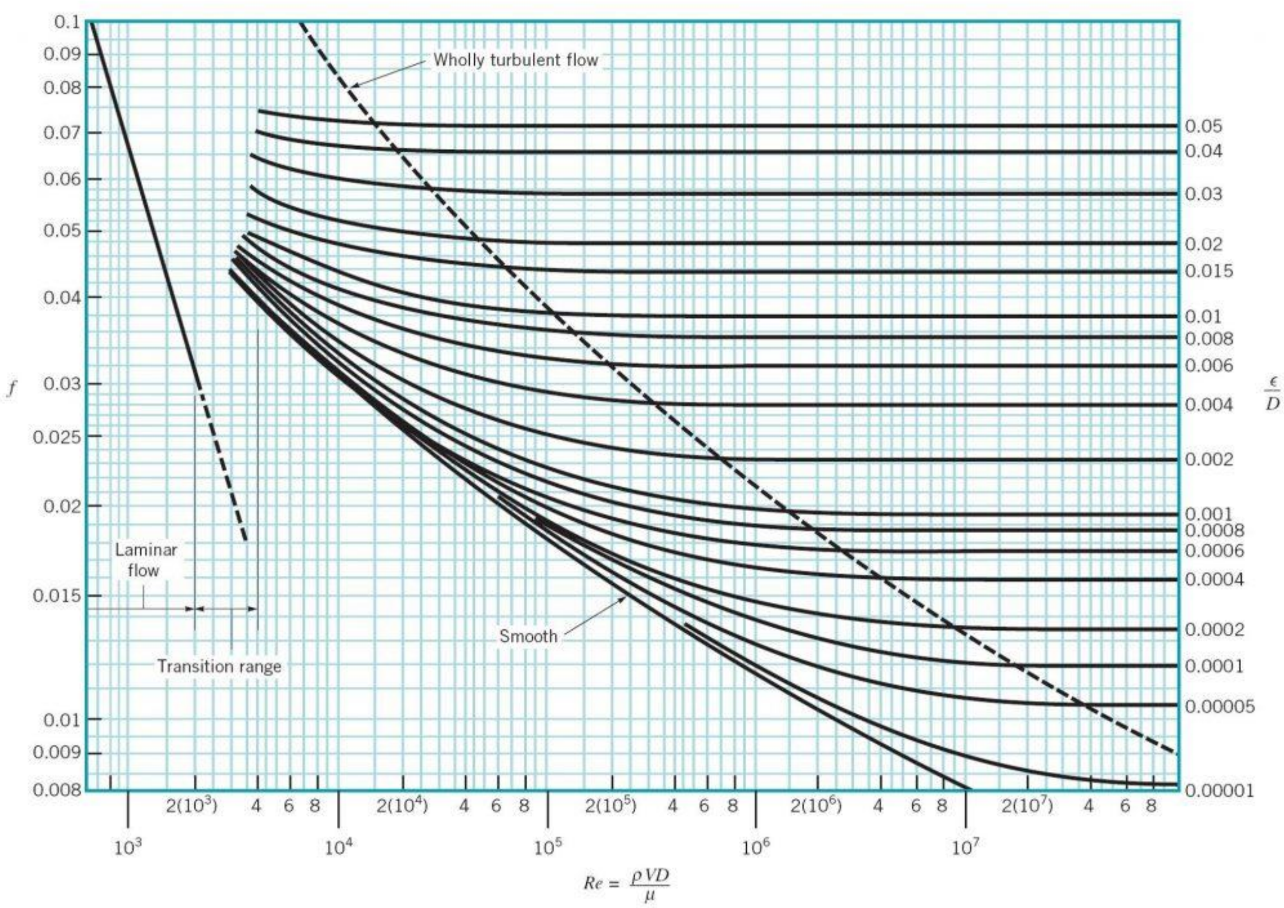


Figure 2-2: Moody's Chart

Instead of using the Moody diagram, f can be determined by utilizing empirical formulas. These formulas are used in engineering applications when computer programs or spreadsheet calculation methods are employed. For turbulent flow in a smooth pipe, a well-known curve fit to the Moody diagram is given by:

$$f = 0.316 Re^{-0.25}$$ **Equation 2-5**

Reynolds number is given by:

$$Re = \frac{\rho v D}{\mu} = \frac{vD}{\nu}$$ **Equation 2-6**

where v is the average velocity, D is the pipe diameter, and μ and ν are dynamic and kinematic viscosities of the fluid, respectively.

In this experiment, h_L is measured directly by the water manometers and the differential pressure gauge that are connected by pressure tappings to the test pipe. The average velocity, v, is calculated from the volumetric flow rate (Q) as:

$$v = \frac{Q}{\frac{\pi D^2}{4}}$$ **Equation 2-7**

The following dimensions from the test pipe may be used in the appropriate calculations:
Length of test pipe = _,
Diameter of test pipe = _.

2.8 EXPERIMENTAL PROCEDURE

The experiment will be performed in two parts: high flow rates and low flow rates. Set up the equipment as follows:

- Mount the test rig on the hydraulics bench, and adjust the feet with a spirit level to ensure that the baseplate is horizontal and the manometers are vertical.
- Attach Hoffman clamps to the water manometers and pressure gauge connecting tubes, and close them off.

2.8.1 High Flow Rate Experiment

The high flow rate will be supplied to the test section by connecting the equipment inlet pipe to the hydraulics bench, with the pump turned off. The following steps should be followed.

i.) Close the bench valve, open the apparatus flow control valve fully, and start the pump. Open the bench valve progressively, and run the flow until all air is purged.

ii.) Remove the clamps from the differential pressure gauge connection tubes, and purge any air from the air-bleed valve located on the side of the pressure gauge.

iii.) Close off the air-bleed valve once no air bubbles observed in the connection tubes.

iv.) Close the apparatus flow control valve and take a zero-flow reading from the pressure gauge.

v.) With the flow control valve fully open, measure the head loss shown by the pressure gauge.

vi.) Determine the flow rate by timed collection.

vii.) Adjust the flow control valve in a step-wise fashion to observe the pressure differences at 0.05 bar increments. Obtain data for ten flow rates. For each step, determine the flow rate by timed collection.

viii.) Close the flow control valve, and turn off the pump.

The pressure difference measured by the differential pressure gauge can be converted to an equivalent head loss (h_L) by using the conversion ratio:

1 bar = 10.2 m water

2.8.2 Low Flow Rate Experiment

i.) The low flow rate will be supplied to the test section by connecting the hydraulics bench outlet pipe to the head tank with the pump turned off. Take the following steps.

ii.) Attach a clamp to each of the differential pressure gauge connectors and close them off.

iii.) Disconnect the test pipe's supply tube and hold it high to keep it filled with water.

iv.) Connect the bench supply tube to the head tank inflow, run the pump, and open the bench valve to allow flow. When outflow occurs from the head tank snap connector, attach the test section supply tube to it, ensuring that no air is entrapped.

v.) When outflow occurs from the head tank overflow, fully open the control valve.

vi.) Remove the clamps from the water manometers' tubes and close the control valve.

vii.) Connect a length of small bore tubing from the air valve to the volumetric tank, open the air bleed screw, and allow flow through the manometers to purge all of the air from them. Then tighten the air bleed screw.

viii.) Fully open the control valve and slowly open the air bleed valve, allowing air to enter until the manometer levels reach a convenient height (in the middle of the manometers), then close the air vent. If required, further control of the levels can be achieved by using a hand pump to raise the manometer air pressure.

ix.) With the flow control valve fully open, measure the head loss shown by the manometers.

x.) Determine the flow rate by timed collection.

xi.) Obtain data for at least eight flow rates, the lowest to give h_L= 30 mm.

xii.) Measure the water temperature, using a thermometer.

2.9 RESULTS AND CALCULATIONS

2.9.1 RESULTS

Record all of the manometer and pressure gauge readings, water temperature, and volumetric measurements, in the Raw Data Tables.

2.9.2 Raw Data Tables: High Flow Rate Experiment

Test No.	Head Loss (bar)	Volume (Litres)	Time (s)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

2.9.3 Raw Data Tables: Low Flow Rate Experiment

Test No.	h_1 (m)	h_2 (m)	Head loss h_L (m)	Volume (litres)	Time (s)
1					
2					
3					
4					
5					
6					
7					
8					
Water Temperature:					

2.10 CALCULATIONS

Calculate the values of the discharge; average flow velocity; and experimental friction factor, *f* using Equation 2-3, and the Reynolds number for each experiment. Also, calculate the theoretical friction factor, *f*, using Equation 2.4 for laminar flow and 2.5 for turbulent flow for a range of Reynolds numbers. Record your calculations in the following sample Result Tables.

Result Table- Experimental Values

Test No.	Head loss hL (m)	Volume (liters)	Time (s)	Discharge (m3/s)	Velocity (m/s)	Friction Factor, f	Reynolds Number
1							
2							
3							
4							
5							

6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							

Table 2-1: Result Table- Theoretical Values

No.	Flow Regime	Reynolds Number	Friction Factor, f
1	Laminar (Equation 2.4)	100	
2		200	
3		400	
4		800	
5		1600	
6		2000	
7	Turbulent (Equation 2.5)	4000	
8		6000	
9		8000	
10		10000	
11		12000	
12		16000	
13		20000	

2.11 REPORT

Use the template provided to prepare your lab report for this experiment. Your report should include the following:

- Table(s) of raw data
- Table(s) of results
- Graph(s)
  - On one graph, plot the experimental and theoretical values of the friction factor, f (y-axis) against the Reynolds number, Re (x-axis) on a log-log scale. The experimental results should be divided into three groups (laminar, transitional, and turbulent) and plotted separately. The theoretical values should be divided into two groups (laminar and turbulent) and also plotted separately.
  - On one graph, plot h_L (y-axis) vs. average flow velocity, v (x-axis) on a log-log scale.
- Discuss the following:
  - Identify laminar and turbulent flow regimes in your experiment. What is the critical Reynolds number in this experiment (i.e., the transitional Reynolds number from laminar flow to turbulent flow)?

- Assuming a relationship of the form $f=KRe^n$, calculate K and n values from the graph of experimental data you have plotted, and compare them with the accepted values shown in the Theory section (Equation 2.4 and 2.5). What is the cumulative effect of the experimental errors on the values of K and n?
- What is the dependence of head loss upon velocity (or flow rate) in the laminar and turbulent regions of flow?
- What is the significance of changes in temperature to the head loss?
- Compare your results for f with the Moody diagram (Figure 2-2: Moody’s Chart). Note that the pipe utilized in this experiment is a smooth pipe. Indicate any reason for lack of agreement.
- What natural processes would affect pipe roughness?

3 TO DETERMINE THE OPERATION CHARACTERSTICS OF THREE DIFFERENT TYPES OF FLOW METERS

3.1 Introduction

Flow measurement is an important topic in the study of fluid dynamics. It must be made in chemical plants, refineries, power plants, and any other place where the quality of the product or performance of the plant depends on having a precise flow rate. Flow measurements also enter into our everyday lives in the metering of water and natural gas into our homes and gasoline into our cars. There are many instruments used in flow measurements. In this experiment, we are going to use the following devices:

1) Venturi meter.

2) Orifice plate.

3) Variable Area meter (Rotameter).

3.2 Objectives

This experiment aims to:

1- Familiarize students with some common devices and methods used in measuring flow rate.
2- Each flow measurement device will be compared to the standard method of using the catch-tank and stopwatch to measure the flow rate.
3- Determine the energy loss incurred by each of these devices.
4- Determine the energy loss arising in a rapid enlargement and a 90^{o} elbow.

3.3 Apparatus

The equipment consists of a Venturi meter, variable area flowmeter and orifice plate installed in a series configuration to permit direct comparison. A flow control valve permits variation of the flow rate through the circuit. Pressure tappings are incorporated so that the head loss characteristics of each flow meter may be measured. These tappings are connected to an eight-tube manometer bank incorporating a manifold with an air bleed valve. Pressurisation of the manometers is facilitated by a hand pump. The circuit and manometer are attached to a support framework, which stands on the working top of the hydraulics bench. The hydraulics bench is used as the source of water supply and for volumetrically calibrating each flow meter.

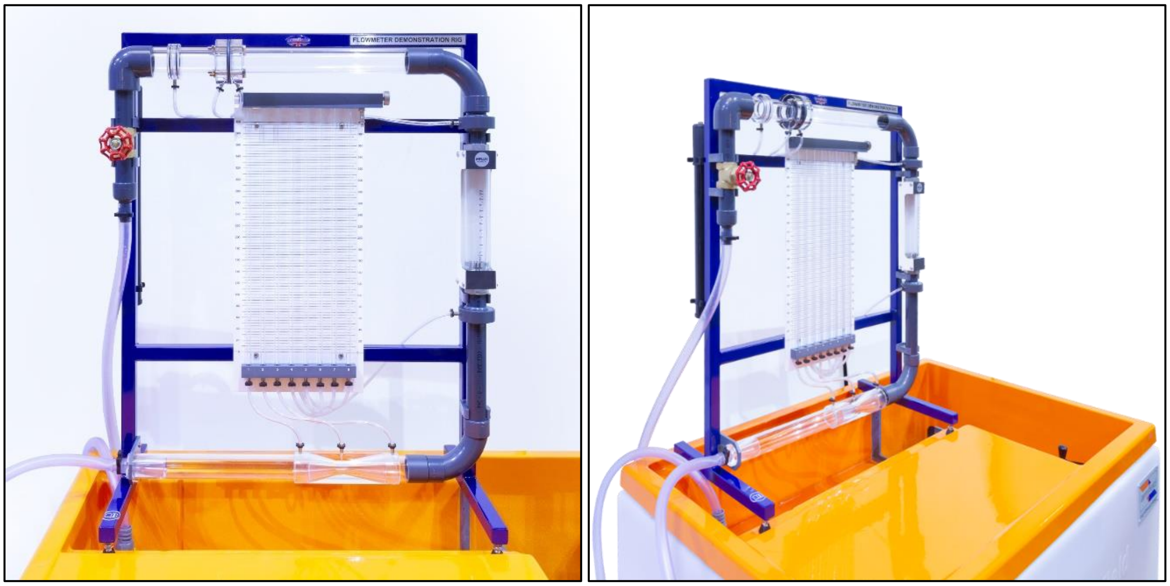


Figure 3-1: Flow measurement Apparatus

3.4 Theory

For steady, adiabatic flow of an incompressible fluid along a stream tube, as shown in figure (3), Bernoulli's equation between points 1 and 2 can be written in the form

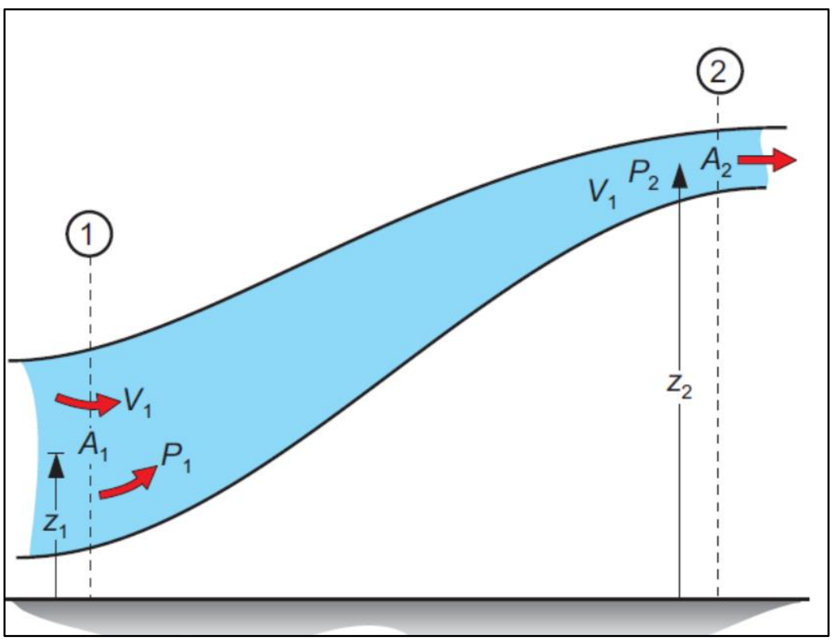


Figure 3-2: Schematic of Bernoulli's Theorem

$$\frac{P_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{P_2}{\rho g}+\frac{v_2^2}{2g}+z_2+\Delta h_{12} \qquad \textbf{Equation 3-1}$$

Where,

$\frac{P}{\rho g} = \text{Hydraulic Head}$

$\frac{V^2}{2g} = \text{Kinetic Head } (V = Q/A)$

$z = \text{Potential Head}$

$\frac{P}{\rho g} + \frac{v^2}{2g} + z = \text{Total Head}$

The head loss *ΔH12* may be assumed to arise as a consequence of the vortices in the stream. Because the flow is viscous a wall shear stress exists and a pressure force must be applied to overcome it. The consequent increase in flow work appears as an increase in internal energy, and because the flow is viscous, the velocity profile at any section is non-uniform.

3.5 Flow measurement

3.5.1 Venturi meter:

In the converging section of the Venturi meter, the flow is accelerated continuously, and therefore, the losses are considered small. Since ΔH12 is negligibly small between the ends of a contracting duct it, along with the Z terms, can be omitted from equation (1) between stations (A) and (B). The discharge is given by:

$$Q = A_B V_B = A_B \sqrt{\left(\frac{2g}{1-\left(\frac{A_B}{A_A}\right)^2}\right)\left(\frac{P_A}{\rho g}-\frac{P_B}{\rho g}\right)} = A_B \sqrt{\left(\frac{2g}{1-\left(\frac{A_B}{A_A}\right)^2}\right)(h_A - h_B)} \qquad \textbf{Equation 3-2}$$

Such that the diameters (bores) of the meter at (A) and (B) are 26 mm and 16 mm respectively. Also, $\frac{P_A}{\rho g}$ and $\frac{P_B}{\rho g}$ are the respective heights of the manometric tubes A and B in meters.

3.5.2 Orifice meter:

The orifice meter is a plate with a central hole introduced into the flow path, see figure (4). It is the easiest and cheapest to install the plate between existing pipe flanges. However, the energy loss (*ΔH12*) associated with the orifice meter is large. The mechanical energy equation between E and F gives:

$$\frac{V_F^2}{2g}-\frac{V_E^2}{2g}=\left(\frac{P_E}{\rho g}-\frac{P_F}{\rho g}\right)-\Delta H_{12}$$ **Equation 3-3**

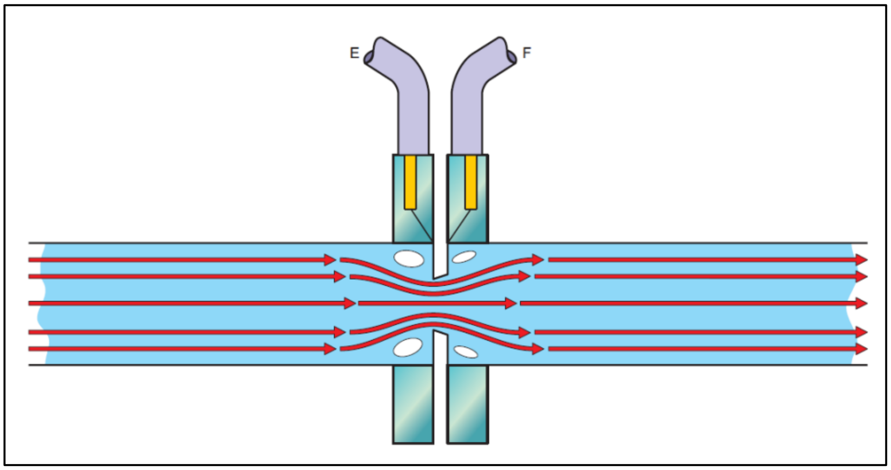


Figure 3-3: Schematic of Orifice Meter

Such that the effect of the head loss is to make the difference in manometric height (h_E - h_F) less than it would otherwise be. An alternative expression is:

$$\frac{V_F^2}{2g}-\frac{V_E^2}{2g}=C^2\left(\frac{P_E}{\rho g}-\frac{P_F}{\rho g}\right)$$ **Equation 3-4**

Where C is the coefficient of discharge which depends on the geometry of the orifice meter. For the apparatus provided, C is given as 0.601. Reducing Equation 3-4 it can be given as follows:

$$Q=A_FV_F=CA_F\sqrt{\left(\frac{2g}{1-\left(\frac{A_F}{A_E}\right)^2}\right)\left(\frac{P_E}{\rho g}-\frac{P_F}{\rho g}\right)}=CA_F\sqrt{\left(\frac{2g}{1-\left(\frac{A_F}{A_E}\right)^2}\right)(h_E-h_F)}$$ **Equation 3-5**

With the apparatus provided, the diameter (bore) at (E) is 51.9 mm. At (F), the water diameter (not the bore) is 20 mm.

3.5.3 Rotameter:

Observation of the recordings for the pressure drop across the rotameter (H) - (I) shows that this difference is large and virtually independent of discharge. There is a term, which arises because of wall shear stresses, and is therefore velocity dependent, but since the rotameter is of large bore this term is small. Most of the observed pressure difference is required to maintain the float in equilibrium and since the float is of constant weight, this pressure difference is independent of discharge. See Figure 3-4.

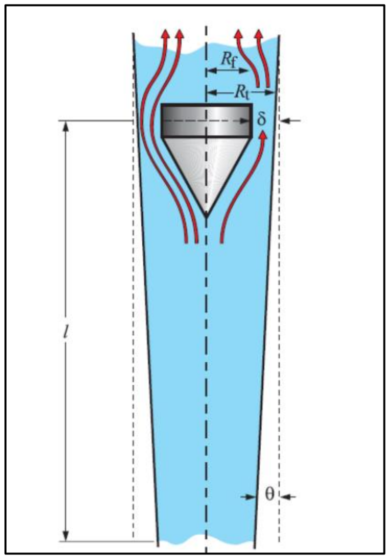


Figure 3-4: Schematic of Rotameter

The cause of this pressure difference is the head loss associated with the high velocity of water around the float periphery. Since this head loss is constant then the peripheral velocity is constant. To maintain a constant velocity with varying discharge rate, the cross-sectional area through which this high velocity occurs must vary. This variation of cross-sectional area will arise as the float moves up and down the tapered rotameter tube. From Figure 3-4, if the float radius is R_f and the local diameter (bore) of the rotameter tube is $2R_t$ then:

$$\pi\left(R_t^2 - R_f^2\right) = 2R_f^2\delta = \text{Cross Sectional Area} = \frac{\text{Discharge}}{\text{Constant Peripheral Velocity}}$$ **Equation 3-6**

Now, where l is the distance from datum to the cross-section at which the local bore is Rt and θ is the semi-angle of tube taper. Hence l is proportional to discharge. An approximately linear calibration characteristic would be anticipated for the rotameter, see figure (6)

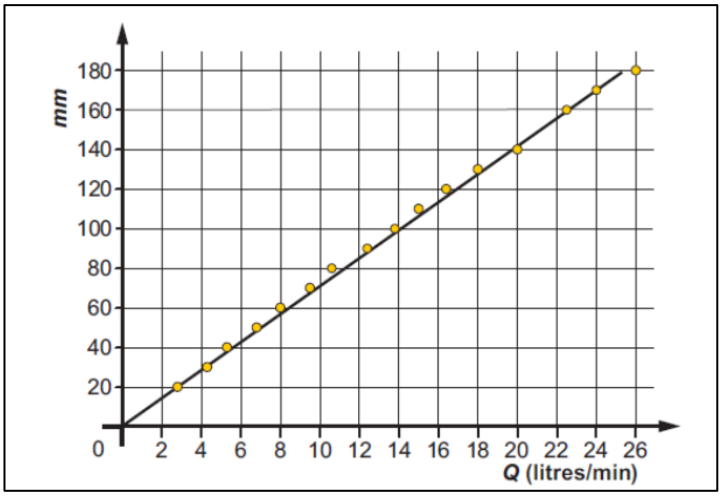


Figure 3-5: Calibration Curve of Rotameter

3.6 Energy losses

3.6.1 Venturi meter:

The head loss associated with Venturi meter can be evaluated by applying Equation 3.1 between pressure tappings (A) and (C):

$$\frac{P_A}{\rho g} - \frac{P_C}{\rho g} = \Delta H_{AC} \Rightarrow h_A - h_C = \Delta H_{AC} \qquad \textbf{Equation 3-7}$$

Equation 3.7 can be made dimensionless by dividing it by the inlet kinetic head $\frac{v_A^2}{2g}$

$$V_B^2 = \left(\frac{2g}{1 - \left(\frac{A_B}{A_A} \right)^2} \right) \left(\frac{P_A}{\rho g} - \frac{P_B}{\rho g} \right) \qquad \textbf{Equation 3-8}$$

$$V_A^2 = V_B^2 \left(\frac{A_B}{A_A} \right)^2 \qquad \textbf{Equation 3-9}$$

$$\frac{V_A^2}{2g} = \left(\frac{A_B}{A_A} \right)^2 \left(\frac{1}{1 - \left(\frac{A_B}{A_A} \right)^2} \right) \left(\frac{P_A}{\rho g} - \frac{P_B}{\rho g} \right) \qquad \textbf{Equation 3-10}$$

3.6.2 Orifice meter:

The head loss associated with the orifice meter can be evaluated by applying equation (1) between (E) and (F) by substituting kinetic and hydrostatic heads would give an elevated value to the head loss for the meter. This is because at an obstruction such as an orifice plate, there is a small increase in pressure on the pipe wall due to part of the impact pressure on the plate being conveyed to the pipe wall. Equation (8) is an approximate expression for finding the head loss which can be taken as 0.83 times the measured head difference

$$\Delta H_{EF} = 0.83\left(h_E - h_F\right)$$ **Equation 3-11**

The orifice plate diameter (51.9 mm) is approximately twice the Venturi inlet diameter (26 mm), therefore the orifice inlet kinetic head is approximately 1/16 that of the Venturi, i.e. $\frac{1}{16}\left(\frac{v_A^2}{2g}\right)$

3.6.3 Rotameter

For this meter, application of $\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + \Delta h_{12}$ Equation 3-1

gives

$$\left(\frac{P_H}{\rho g} + z_H\right) - \left(\frac{P_I}{\rho g} + z_I\right) = \Delta H_{HI}$$ **Equation 3-12**

Then, as illustrated in figure (7):

$$h_H - h_I = \Delta H_{HI}$$ **Equation 3-13**

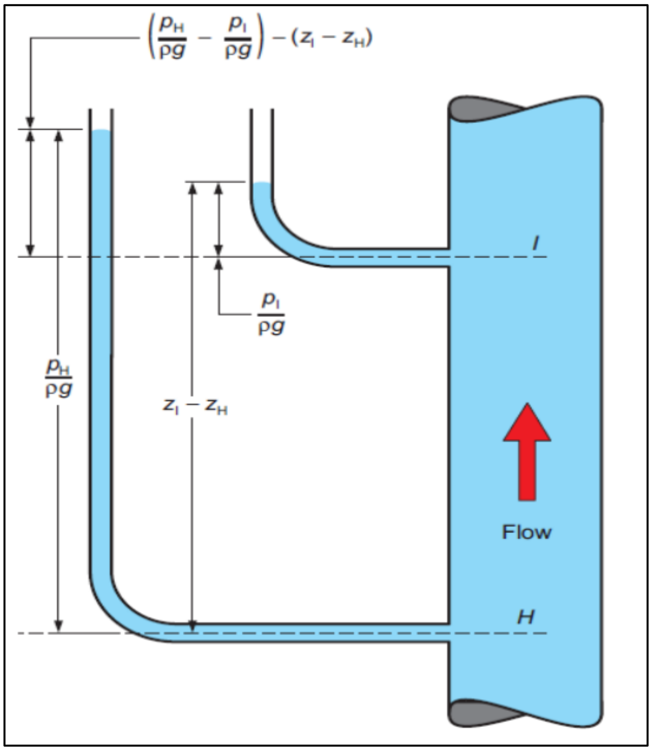


Figure 3-6: Schematic of orifice meter

Inspection of the table of experimental results shows that this head loss is virtually independent of discharge and has a constant value of approximately 100 mm of water. As has already been shown, this is a characteristic property of the rotameter. For comparative purposes it could be expressed in terms of the inlet kinetic head. However, when the velocity is very low the head loss remains the same and so becomes many, many times the kinetic head. It is instructive to compare the head losses associated with the three meters with those associated with the rapidly diverging section, or wide-angled diffuser, and with the right-angled bend or elbow. The same procedure is adopted to evaluate these losses

3.6.4 Wide-angled diffuser

The inlet to the diffuser may be considered to be at (C) and the outlet at (D). Applying Equation 3-1

$$\frac{P_C}{\rho g} + \frac{V_C^2}{2g} = \frac{P_D}{\rho g} + \frac{V_D^2}{2g} + \Delta H_{CD}$$ **Equation 3-14**

Since the area ratio, inlet to outlet, of the diffuser is 1:4 the outlet kinetic head is 1/16 of the inlet kinetic head.

3.6.5 Right-angled bend

The inlet to the bend is at (G) where the pipe bore is 51.9 mm and outlet is at (H) where the bore is 40 mm. Applying Equation 3-1

$$\frac{P_G}{\rho g} + \frac{V_G^2}{2g} = \frac{P_H}{\rho g} + \frac{V_H^2}{2g} + \Delta H_{GH}$$ **Equation 3-15**

The outlet kinetic head is now 2.8 times the inlet kinetic head.

3.7 Experimental Procedures

Part 1: Flow Measurements and Head Losses

1. Make sure the air purge valve is closed.
2. Close the control valve of the flow measurement apparatus fully, then open it by about 1/3.
3. Switch on the hydraulic bench pump.

4. Slowly open the hydraulic bench valve until water starts to flow. Allow the flow measurement apparatus to fill with water.
5. Open the bench valve fully, and then close the control valve of the flow measurement apparatus.
6. Open the valve of the flow measurement apparatus (1/4 turn ONLY).
7. Connect the hand pump to the air purge valve and pump until all the manometers read approximately 330 mm.
8. Dislodge any entrapped air from the manometers by gentle tapping with the fingers.
9. Check that the water levels are constant. The levels will rise slowly if the purge valve is leaking.
10. Open the apparatus valve until the rotameter shows a reading of approximately 10 mm.
11. When a steady flow is maintained measure the flow with the hydraulic bench as follows:
    a. Direct the outlet of your experiment to the volumetric tank.
    b. Start your stopwatch as soon as the water level in the volume indicator reaches
    c. Stop your stopwatch when the level in the volume indicator reaches 10.
12. Record the readings of the manometers in table (1).
13. Repeat steps 10-12 for 10 tests.
14. Increase the opening of the apparatus valve such that the rotameter reading is increased in steps of 10 mm

		Test Number									
		1	2	3	4	5	6	7	8	9	10
	A										
	B										
Manometer Levels	C										
	D										
	E										
	F										
	G										
	H										
	I										
Rotameter (cm)											
Water *W* (kg)											
Time *T* (seconds)											
Mass Flow Rate m (kg/s)	Venturi										
	Orifice										
	Rotameter										
	Weigh Tank										
ΔH/Inlet Kinetic Head	Venturi										
	Orifice										
	Rotameter										
	Diffuser										
	Elbow										

3.8 Discussion and Conclusions

1. What is the accuracy of each device compared with the flow rate measured by the hydraulic bench? Based on your results, which device would you recommend for flow measurement?
2. Discuss the advantages and disadvantages of each device.
3. Explain why the rotameter must have a slightly diverging cross-section

4 TO DETERMINE THE CHARACTERSTICS OF FLOW OVER A RECTANGULAR NOTCH

4.1 INTRODUCTION

A weir is a barrier across the width of a river or stream that alters the characteristics of the flow and usually results in a change in the height of the water level. Several types of weirs are designed for application in natural channels and laboratory flumes. Weirs can be broad-crested, short-crested, or sharp-crested. Sharp-crested weirs, commonly referred to as *notches*, are manufactured from sharp-edged thin plates. The relationship between the flow rate and water depth above the weir can be derived by applying the Bernoulli's equation and by making some assumptions with regard to head loss and pressure distribution of the flow passing over the weir. A coefficient of discharge needs to be determined experimentally for each weir to account for errors in estimating the flow rate that is due to these assumptions.

4.2 PRACTICAL APPLICATION

Weirs are commonly used to measure or regulate flow in rivers, streams, irrigation canals, etc. Installing a weir in an open channel system causes critical depth to form over the weir. Since there is a unique relationship between the critical depth and discharge, a weir can be designed as a flow-measuring device. Weirs are also built to raise the water level in a channel to divert the flow to irrigation systems that are located at higher elevations.

4.3 OBJECTIVE

The objective of this experiment is to determine the characteristics of flow over a rectangular weir,

4.4 METHOD

The coefficients of discharge are determined by measuring the height of the water surface above the notch base and the corresponding flow rate. The general features of the flow can be determined by direct observation.

4.5 EQUIPMENT

The following equipment is required to perform the flow over weirs experiment:

- F1-10 hydraulics bench;
- F1-13 rectangular and triangular weirs;
- Vernier height gauge; and
- Stopwatch.

4.6 EQUIPMENT DESCRIPTION

The flow over the weir apparatus includes the following elements that are used in conjunction with the flow channel in the molded bench top of the hydraulics bench (Figure 4-1).

- A combination of a stilling baffle and the inlet nozzle to promote smooth flow conditions in the channel.
- A vernier hook and point gauge, mounted on an instrument carrier, to allow measurement of the depth of flow above the base of the notch.
- The weir notches that are mounted in a carrier at the outlet end of the flow channel [9].

Figure 4-1: Hydraulics bench and weir apparatus

4.7 THEORY

The depth of water above the base of a weir is related to the flow rate through it; therefore, the weir can be used as a flow measuring device. The relationships of flow over weirs can be obtained by applying the energy equation from a point well upstream of the weir to a point just above the weir crest. This approach requires a number of assumptions, and it yields the following results:

- for a rectangular weir (Figure 4-1):

$$Q = C_d \frac{2}{3}\sqrt{2g}bH^{\frac{3}{2}}$$ **Equation 4-1**

where:

Q: flow rate;

H: height above the weir base;

b: width of rectangular weir (R-notch);

C_d: discharge coefficient to account for the effects of simplifying assumptions in the theory, which has to be determined by experiment.

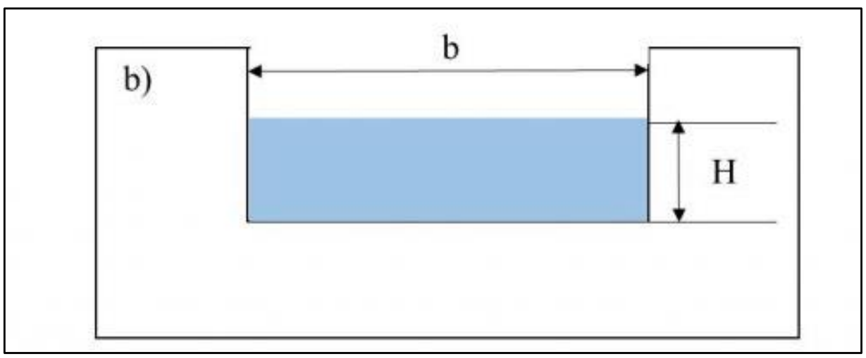


Figure 4-2: Rectangular weir

- for a R-notch:

$$C_d = \frac{3Q}{2\sqrt{2g}bH^{\frac{3}{2}}}$$ **Equation 4-2**

4.8 EXPERIMENTAL PROCEDURE

This experiment will be performed by taking the following steps:

1. Ensure that the hydraulics bench is positioned so that its surface is horizontal. This is necessary because the flow over the notch is driven by gravity.
2. Mount the rectangular notch plate onto the flow channel, and position the stilling baffle as shown in Figure 4-3Turn on the pump, and slightly adjust the flow control to fill the channel upstream of the weir with water.

3. Turn off the pump when the water starts to flow over the weir.
4. Wait a few minutes to allow the water to settle.
5. Level the point gauge with the water level in the channel. Record the reading as ho.

Note: To measure the datum height of the base of the notch (ho), position the instrument carrier as shown in Figure 9.3. Then carefully lower the gauge until the point is just above the notch base, and lock the coarse adjustment screw. Then, using the fine adjustment, adjust the gauge until the point just touches the water surface and take a reading, being careful not to damage the notch.

- Adjust the point gauge to read 10 mm greater than the datum.
- Record the reading as h.
- Turn on the pump, and slightly adjust the flow until the water level coincides with the point gauge. Check that the level has stabilized before taking readings.
- Measure the flow rate using the volumetric tank.
- Observe the shape of the nappe and take pictures of it.

Note*:* The surface of the water will fall as it approaches the weir. This is particularly noticeable at high flow rates by high heads. To obtain an accurate measurement of the undisturbed water level above the crest of the weir, it is necessary to place the measuring gauge at a distance of at least three times the head above the weir.

- Increase the flow by opening the bench regulating valve to set the heads above the datum level in 10 mm increments until the regulating valve is fully open. Take care not to allow spillage to occur over the plate top that is adjacent to the notch. At each condition, measure the flow rate and observe the shape of the nappe.

Note: To obtain a sufficiently accurate result, collect around 25 liters of water each time, or collect the water for at least 120 seconds.

- Close the regulating valve, stop the pump, and then replace the weir with the V-notch.
- Repeat the experiment with the V-notch weir plate, but with 5 mm increments in water surface elevation.
- Collect seven head and discharge readings for each weir.

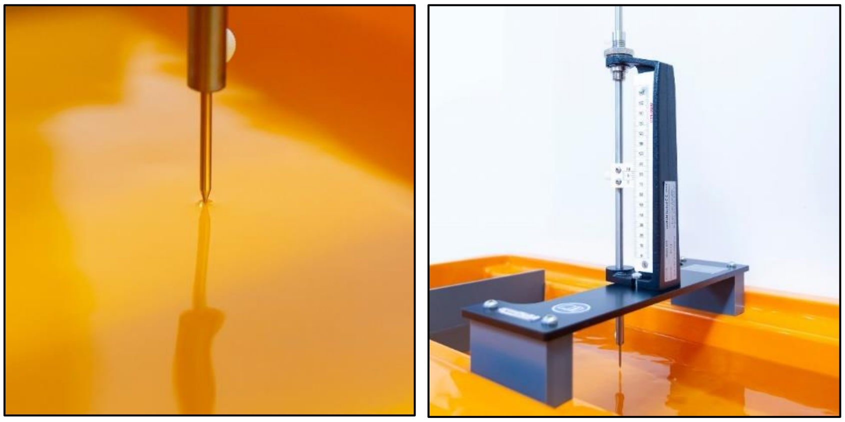


Figure 4-3: Position of the notch and Vernier height gauge to set the datum.

4.9 RESULTS AND CALCULATIONS

4.9.1 RESULT

Use the following tables to record your measurements. Record any observations of the shape and the type of 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 4-4 to classify the nappe).

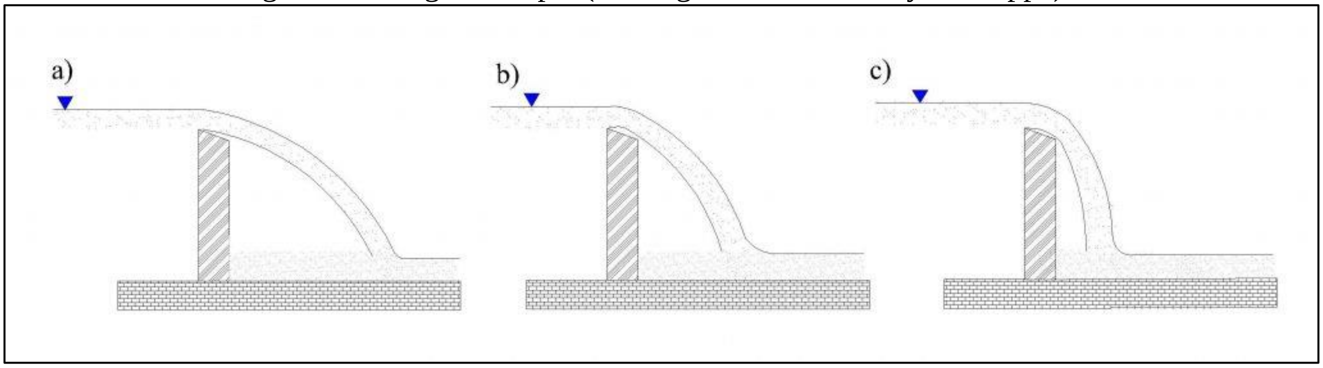


Figure 4-4: Types of nappe: a) Springing clear nappe, b) Depressed Nappe, and c) Clinging Nappe

Table 4-1: Raw Data Table: R-notch

Test No.	Datum Height ho (m)	Water Surface Elev. h(m)	Volume Collected (L)	Time for Collection (s)
1				
2				
3				
4				
5				
6				
7				

4.10 CALCULATIONS

- The following dimensions from the equipment can be used in the appropriate calculations:
  - width of rectangular notch (b) = 0.03 m
- Calculate discharge (Q) and head (h) for each experiment, and record them in the Result 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., $H = h\text{-}h_o$
- Calculate $H^{3/2}$ for the rectangular notch.
- For each measurement, calculate the experimental values of Cd from Equation 4-2
- Record your calculations in the Results Tables.

Result Table: R-notch

No.	H (m)	Volume Collected (m3)	Flow Rate (m3/s)	$H^{3/2}$	Experimental Cd	Theoretical Cd	%Error
1							
2							
3							
4							
5							
6							
7							

4.11 REPORT

- Use the template provided to prepare your lab report for this experiment. Your report should include the following:
- Table(s) of raw data
- Table(s) of results
- Graph(s)
  - 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. Use a linear function to plot the best fit, and express the relationship between Q and H^n and in the form of: $Q = mH^n$ in which the exponent value n is 1.5 for the rectangular weir. Calculate the coefficients of discharge C_d (theoretical method). Record C_d values calculated from the theoretical method in the Result Tables.

for a rectangular notch:

$$C_d = \frac{m}{\frac{2}{3}\sqrt{2g}b}$$

- Compare the experimental results to the theory by calculating the percentage of error.
- What are the limitations of the theory?
- Why would you expect wider variation of C_d values at lower flow rates?

- Compare the results for C_d of the weirs utilized in this experiment with those you may find in a reliable source (e.g., textbooks). Include in your report a copy of the tables or graphs you have used for textbook values of C_d.
- Discuss your observations and any source of errors in calculation of C_d.

5 TO DETERMINE THE OPERATING CHARACTERSTICS OF A PELTON WHEEL TURBINE AT VARIOUS SPEEDS

5.1 Purpose:

To investigate the performance characteristics of an Impulse Turbine (Pelton wheel), and compare with its ideal efficiency curve.

5.2 Introduction:

Pelton wheel is impulse type water turbine which extracts energy from impulse of moving water when the water strikes the pelton cup at very high speed, it induces an impulsive force which makes the turbine rotate. In short the pelton wheel transforms the kinetic energy of water jet into rotational energy.

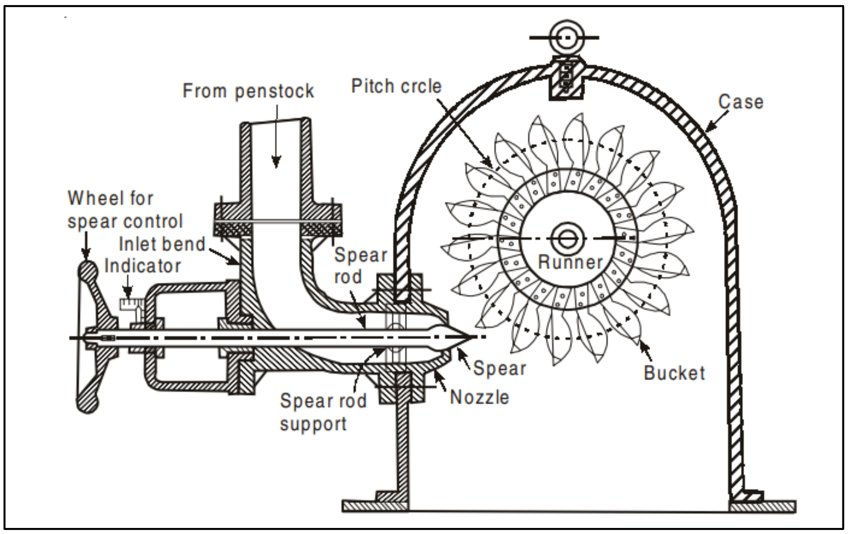


Figure 5-1 : Schematic of Pelton Wheel Turbine

The spoon shaped buckets are mounted on the circumferential rim of drive wheel called runner. As the high-speed jet of water impinges upon the pelton cups, the direction of the water velocity is changed to follow the contour of the bucket. The impulse energy of water exerts torque on the bucket and makes the wheel to spin, and finally the water takes U-turn and exits at the sides of pelton cup with low velocity. The tangential action turbine with partial charge is very sensible at the geometrical deviation of the real jet from the theoretical axis. The possible error from the design, assign, assembly, wrong fitting and others, have negative consequences over the turbine performances.

Control of the turbine is maintained by hydraulically operated needle nozzles in each jet. In addition, a jet deflector is provided for emergency shutdown. The deflector diverts the water jet from the buckets to the wall of the pit liner. This feature provides surge protection for the penstock without the need for a pressure relief valve because load can be rapidly removed from the generator without changing the flow rate. Control of the turbine may also be accomplished by the deflector alone. On these units the needle nozzle is manually operated and the deflector diverts a portion of the jet for lower loads. This method is less efficient and normally used for speed regulation of the turbine under constant load.

The main parts of Pelton Turbine are:

5.2.1 Nozzle and Flow regulation arrangement:

The amount of water flowing out from the nozzle is regulated by providing a spear in the nozzle. The spear is a conical shaped needle which is operated by manually or automatically in an axial direction depending upon the size of the unit.

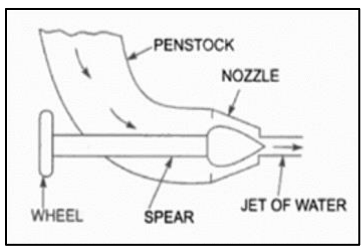


Figure 5-2 :Pelton Turbine Nozzle

5.2.2 Runner and Buckets:

Runner consists of a circular disc on the periphery of which number of buckets are attached with equal spacing. The pelton buckets are in cup or bowl shape and each bucket is divided into symmetrical parts by a wall called splitter. The splitter divides the jet of water into two equal parts. The buckets are designed in such a way that the water jet gets deflected through 160° or 170°. The buckets are made of bronze, cast iron or stainless steel depending upon the head at the inlet of the turbine.

5.2.3 Casing:

The function of water is to prevent the splashing of water and to guide the discharged water to tail race. The casing of Pelton Wheel does not perform any Hydraulic function.

5.2.4 Breaking Jet:

When the nozzle is closed completely by moving the spear in forward direction, the amount of water striking the bucket reduces to zero. But due inertia, the runner goes on revolving for some more time. To stop the runner in a short time, a small nozzle is provided which directs the water from the back of the buckets. This water jet is known as breaking jet.

5.3 Apparatus:

- Armfield Hydraulic Bench,
- Armfield Fl-25
- Pelton turbine demonstration unit,
- stopwatch and
- tachometer.

The turbine demonstration unit sits on top of the hydraulic bench, which circulates water from its reservoir through the turbine. The flow rate is controlled by the spear valve (2), and can be measured by means of a stopwatch and the volumetric gage on the bench. The total water head (in meters) at the turbine inlet is indicated by the pressure gage (1). The slide rod and the lock screw (6) adjust the tension in the belt below the spring balances (5). Rotation speed (in RPM) is measured by a digital tachometer counting the frequency of the marking on the surface of the brake drum on the back side of the turbine.

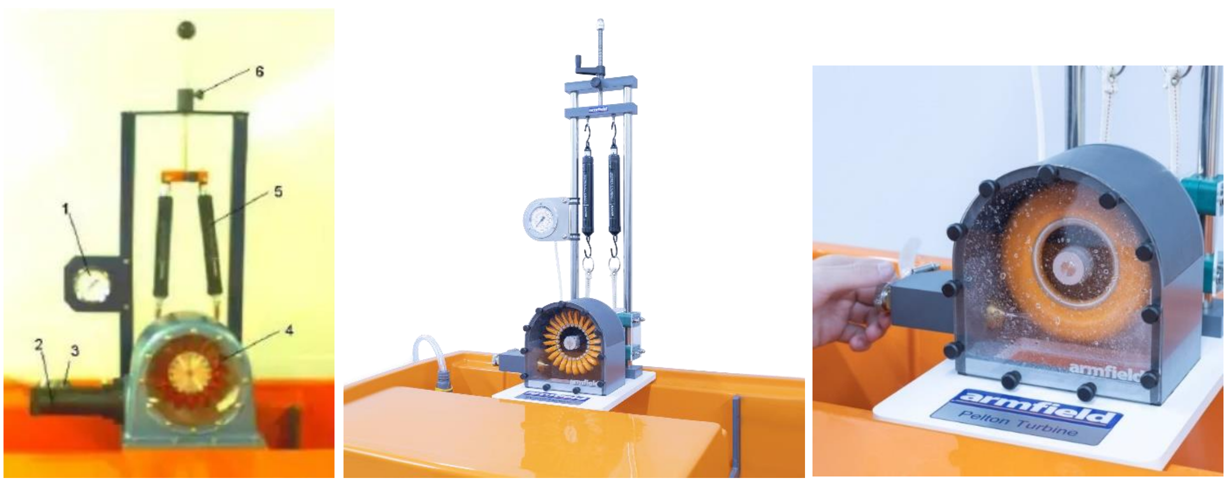


Figure 5-3 : Experimental Setup

5.4 Theory

Apply the continuity equation and energy equation across a Pelton turbine to show that the ideal power available is

$$P_i = \rho g Q \Delta H \qquad \textbf{Equation 5-1}$$

where *P*, Q = fluid density and flow rate, respectively.

$$P_i = \rho g Q \Delta H \qquad \textbf{Equation 5-2}$$

ΔH = total head change across the turbine, which is approximately same as the static head change if the velocity head and elevation head changes are small.

The volumetric flow rate through the turbine:

$$Q_v = \frac{V}{t} \qquad \textbf{Equation 5-3}$$

where Qv is the volumetric flow rate through the turbine, *V* of water flowing through the turbine during time *t*. When the volume of water flows through the turbine, brake force working on the turbine is F_b and the torque *T* that rotates the rotor is given by

$$T = F_b \times r \qquad \textbf{Equation 5-4}$$

where *r* is the radius of the brake pulley (given *r* = 0.03 m). F_b applied on the turbine is given by the readings (ω_1 and ω_2) from two spring balances. So,

$$F_b = \omega_2 - \omega_1 \qquad \textbf{Equation 5-5}$$

Mechanical power Ph, produced by the turbine that is rotating at *n* speed is

$$P_b = 2\pi n T \qquad \textbf{Equation 5-6}$$

Hydraulic power Ph supplied by the water is,

$$P_h = \gamma Q_v H_i \qquad \textbf{Equation 5-7}$$

where H_i is the pressure difference P; [N/m^2] across a turbine such that

$$H_i = \frac{p_i}{\gamma} \qquad \textbf{Equation 5-8}$$

The Bourdon pressure gauge measures the pressure difference relative to the atmospheric pressure. Overall efficiency of the turbine can be calculated from,

$$\eta_t = \frac{Power_{out}}{Power_{in}} \times 100\% = \frac{2\pi nT}{\gamma Q_v H_i} \times 100\% \qquad \textbf{Equation 5-9}$$

5.5 Equipment set up

1. Position the apparatus above the working channel of the hydraulic bench as shown in Figure 3.
2. Connect the flexible tube of the turbine apparatus (inlet pipe in Figure 5-3) at the hydraulic bench supply connector.
3. The tachometer will be used to find the speed of the turbine.
4. A band brake assembly will be used to apply force on the turbine and change operating speed of the turbine. First, add the band brake assembly and lower it until the brake is clear of the brake drum.

5.6 Procedure

1. First, close the bench flow control valve and keep the spear valve closed but do not force it shut.
2. Turn the switch of the bench pump and open the bench control valve fully.
3. Gradually open the spear valve.
4. At this stage, band brake assembly is around the brake drum and tension in both the spring balances is 0 mark (both the spring balances should read 0). With 0 mark applied, the turbine operates at maximum speed.
5. Find this maximum speed of the turbine using the tachometer. Place the tachometer horizontally to read the reading in the tachometer. A stabilized number in the tachometer is the correct motor speed.
6. When the turbine is operating at maximum speed, find the flow rate through the turbine using a stop watch and collecting 4 L of water in the hydraulic bench.
7. Record the inlet pressure gauge readings.
8. Next, apply tension in the band brake slightly (i.e., 2 mark) to slow the rotor speed slightly.
9. Use the tachometer to find the speed of the turbine.
10. Record the spring balance readings, pressure gauge readings, and flow rate using stop watch using a stop watch.
11. Increase the tension in the brake and repeat the steps 8 to 10 and collect at least a total of 6 sets

of data. The last data set should be the highest speed at which the rotor has 0 speed.

12. When 6 sets of data are collected with the spear valve completely open, then reduce the flow rate slightly by closing the spear valve and repeat the experiment from steps 1 through 11.

5.7 Calculations

1. Rotor speed (n) is measured in RPM. Convert it to Hz by dividing the reading by 60.

2. Read the force reading $\omega_1$and ω_2, from spring balance 1 and 2, respectively.

3. Find the volumetric flow rate (Q_v) by collecting 4L of water and finding the lime to collect that amount of water - Column 6.

4. Inlet head H_i is calculated from the pressure reading at the Bourdon gauge using the Column 8.

5. Brake force Fb is the difference between $\omega_1$and ω_2,. So, $F_b = \omega_2 - \omega_1$,-Column 9.

6. Torque T can be calculated using $T = F_b \times r$, where r is radius of the drum on which brake band operates and is given as r = 0.03 m. - Column 10.

7. Brake power is calculated using $P_b = 2\pi nT$ - Column 11.

8. Hydraulic power Ph can be calculated using $P_h = \gamma Q_v H_i$ - Column 12.

9. Overall turbine efficiency $\eta_t = \frac{P_b}{P_h} \times 100\%$ - Column 13.

10. Plot a graph of measured Brake Horse Power 1%, Torque T, and overall efficiency for different rotational speed n for a series of volumetric flow rate Q_v.

11. For the case of spear valve partially open, plot a graph of measured Brake Horse Power P_b, Torque T, and overall efficiency for different rotational speed n for a series of volumetric flow rate Q_v.

5.8 Discussions

Discuss your results by addressing the followings-

1. Comment on the shape of the graphs.

2. Compare at what speed maximum torque, maximum power output occurred when the spear valve was completely open, partially open.

3. Discuss if the maximum efficiency is at the same speed when the spear valve was completely open and partially closed.

4. Suggest optimum condition for operation of the Pelton turbine.

6 TO MEASURE DISCHARGE IN OPEN CHANNEL FLOW BY VELOCITY METHOD

6.1 Introduction

General Measurement of discharge is a principal work in hydrographic surveying. In order to design any river engineering work, the discharge and the mean velocity of the river is required. This experiment mainly deals with the measurement of discharge of a channel by the area-velocity method.

6.2 Objectives

- To measure the discharge passing a given cross-section of a rectangular open channel
- To verify the adequacy of two common assumptions regarding the velocity in a vertical cross section used in stream gauging.

6.3 Theory

In the flow of real fluids (such as water) through a channel with rigid boundaries, the velocity distribution across any given cross-section is not uniform, the velocities at points along the boundary being zero and increasing with increasing distance from the boundary. In a rectangular channel, the maximum velocity should ideally occur at the intersection of the mid vertical of the cross section with the free surface. In reality however, the resistance at the air water interface makes the maximum velocity to occur at a point on the mid vertical slightly below the free surface

A distance measurement in an open Channel therefore requires the determination of sufficient point velocities to permit the computation of an average velocity in the stream. The cross-section area multiplied by the average velocity gives the total discharge. In practice however the channel cross-section is divided into number of vertical sections (see figure 1) and the average velocities in each of these vertical sections are calculated by making several point measurements at various depths along the mid vertical of the section and then taking a weighted average of these measured velocityes. The total discharge Q passing the section is then calculated as

$$Q = \sum_{i=1}^{n} Q_i = \sum_{i=1}^{n} V_i A_i$$

Where Qi is the discharge passing, v_i is the weighted average velocity and Ai is the cross sectional area of its vertical section and n is the number of vertical sections into which the channel cross section has been divided.

The weighted average velocity vi is calculated as follows:

$$V_i = \frac{1}{A_i}\sum_{j=1}^{m} u_j a_j$$

Where u_i is the point velocity at the j^{th} measurement point along the mid vertical of the i^{th} vertical section, a_{ij} is the elemental cross sectional area associated with the measuring point and m is the number of velocity measurement points along the i^{th} mid-vertical.

On the basis of numerous field and laboratory tests it has been found the velocity along a vertical of the channel cross section varies approximately as a parabola from zero at the channel bottom to maximum at (or near) the surface. Results of these tests further show that the variation for meet channels is such that the average of the velocities at 0.2 and 0.8 depth below the surface equals the mean velocity in the vertical. (These two assumptions are used in almost all stream gauging in the field).

$$V = \frac{v_{0.2} + v_{0.8}}{2} = v_{0.6} \qquad \textbf{Equation 6-1}$$

6.4 Apparatus

A glass walled open flume fitted with a stilling tank and screens on the entry side, a point gauge mounted on a traversing platform, a pitot static tube (Prandtl type) mounted on a slidable wooden plank and connected to two inclined (30 degrees to the horizontal) open ended glass tubes.

6.5 Procedure

i) Prime the C.F. pump supplying water through the flume & start the pump

ii) Open the inlet valve and allow a steady flow of water through the flume at about 6-10 cm depth.

iii) Immerse the pitot-static tube into the flowing water and remove carefully any air bubble in the two tubing connecting the pitot tube to the inclined piezometer tube and total head tube.

iv) Bring the traversing point-gauge at the mid length of the channel (marked stn ‘0’ by chalk) and set the gauge to read 15 cm depth above the channel bottom at this cross section.

v) Open the inlet valve further and adjust carefully so that under then steady conditions of the water surface just touches the underside fo the point gauge (depth of flow at station ‘o’ is now 15 cm)

vi) Note the reading of the venturimeter.

vii) Remove the point gauge from station ‘O’ and pitot static tube assembly there taking care that the horizontal limb of the pitot tube always remains under water.

viii) Imagine the channel cross section at station ‘O’ to be divided into three equal vertical section (n=3) in equation 1 as shown in Fig 1 and position of the pitot -static tube such that its vertical limb lies in the vertical plane containing the mid-vertical of the 1st section, i.2. l=1. (Take the section to be the one adjacent to the left bank of the channel)

ix) Lower the pitot-static tube assembly such that the horizontal limb just touches the channel bottom. At this lowest position the velocity measurement point (j=1) lies 0.3 cm above the channel bottom.

x) Check if the horizontal limb of the P.S. tube is correctly aligned in the direction of the flow and observe carefully the readings of the two inclined open ended manometer tubes and record them in the appropriate observation-cum calculation tables in the appropriate columns.

xi) Lift the pitot-static tube to the next higher position (j=j+1. Repeat steps 10-11 till the pitot static tube position j=m (11 in the present case) is reached.

xii) Lower the pitot tube assembly by about 3 cm and shift laterally towards the right bank so that the vertical limb of the pitot tube lies in the plane containing the mid vertical of the next vertical section (i=i+1).

xiii) Repeat steps 9-13 till i equals (n=3 in this case) i.e. the measurements along all three verticals are completed.

xiv) Note again the reading of the venturi meter.

6.6 Assignment

Table 6-1: Observation Table Mid vertical of section -1

Height above channel bottom	Total Head (cm)	Static Head (cm)	Dynamic Head (cm)	Point Velocity (cm/s)	Associated flow area ai (cm^2)	Associated discharge qi (cm^3/s)
0.3						
0.6						
1						

2						
3						
4						
6						
8						
10						
12						
14						

Table 6-2: Observation Table Mid vertical of section -2

Height above channel bottom	Total Head (cm)	Static Head (cm)	Dynamic Head (cm)	Point Velocity (cm/s)	Associated flow area ai (cm^2)	Associated discharge qi (cm^3/s)
0.3						
0.6						
1						
2						
3						
4						
6						
8						
10						
12						
14						

Table 6-3: Observation Table Mid vertical of section -3

Height above channel bottom	Total Head (cm)	Static Head (cm)	Dynamic Head (cm)	Point Velocity (cm/s)	Associated flow area ai (cm^2)	Associated discharge qi (cm^3/s)
0.3						
0.6						
1						
2						
3						
4						
6						
8						
10						
12						
14						

7 TO INVESTIGATE THE VALIDITY OF BERNOULIES THEOREM

7.1 INTRODUCTION

Energy presents in the form of pressure, velocity, and elevation in fluids with no energy exchange due to viscous dissipation, heat transfer, or shaft work (pump or some other device). The relationship among these three forms of energy was first stated by Daniel Bernoulli (1700-1782), based upon the conservation of energy principle. Bernoulli's theorem pertaining to a flow streamline is based on three assumptions: steady flow, incompressible fluid, and no losses from the fluid friction. The validity of Bernoulli's equation will be examined in this experiment.

7.2 PRACTICAL APPLICATION

Bernoulli's theorem provides a mathematical means to understanding the mechanics of fluids. It has many real-world applications, ranging from understanding the aerodynamics of an airplane; calculating wind load on buildings; designing water supply and sewer networks; measuring flow using devices such as weirs, Parshall flumes, and venturimeters; and estimating seepage through soil, etc. Although the expression for Bernoulli's theorem is simple, the principle involved in the equation plays vital roles in the technological advancements designed to improve the quality of human life.

7.3 OBJECTIVE

The objective of this experiment is to investigate the validity of the Bernoulli equation when it is applied to a steady flow of water through a tapered duct.

7.4 METHOD

In this experiment, the validity of Bernoulli's equation will be verified with the use of a tapered duct (venturi system) connected with manometers to measure the pressure head and total head at known points along the flow.

7.5 EQUIPMENT

The following equipment is required to complete the demonstration of the Bernoulli equation experiment:

- F1-10 hydraulics bench,
- F1-15 Bernoulli's apparatus test equipment, and
- A stopwatch for timing the flow measurement.

7.6 EQUIPMENT DESCRIPTION

The Bernoulli test apparatus consists of a tapered duct (venturi), a series of manometers tapped into the venturi to measure the pressure head, and a hypodermic probe that can be traversed along the center of the test section to measure the total head. The test section is a circular duct of varying diameter with a 14° inclined angle on one side and a 21° inclined angle on other side. Series of side hole pressure tappings are provided to connect manometers to the test section (Figure 7-1: Bernoulli's Theorem Apparatus).

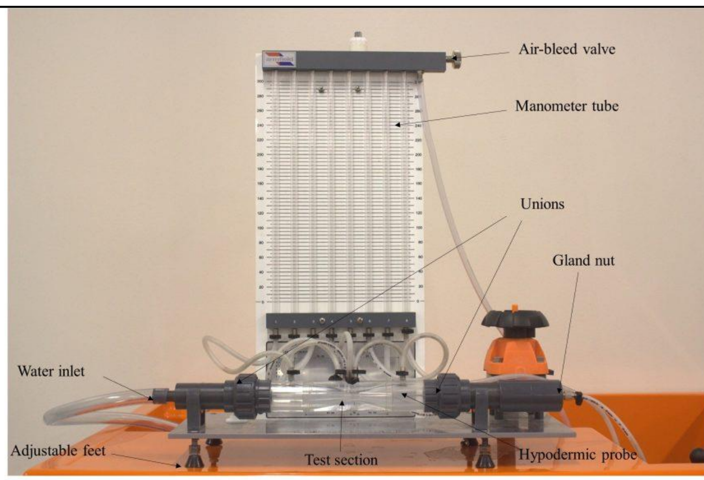
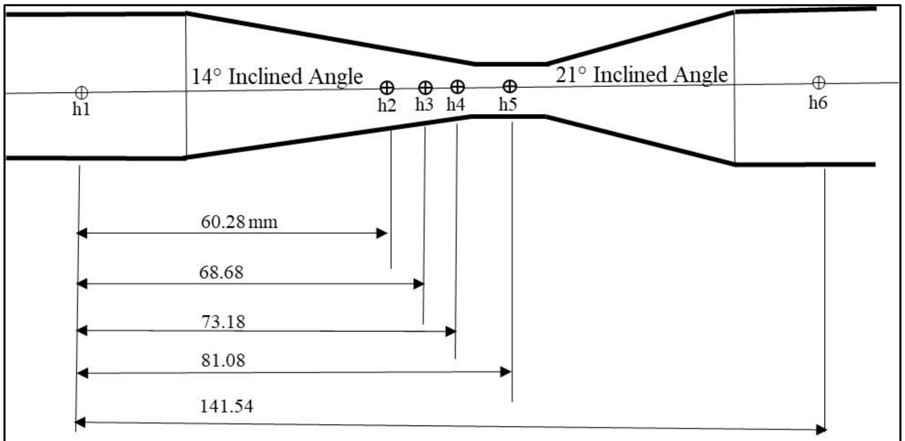


Figure 7-1: Bernoulli's Theorem Apparatus

Manometers allow the simultaneous measurement of the pressure heads at all of the six sections along the duct. The dimensions of the test section, the tapping positions, and the test section diameters are shown in Figure 7-2. The test section incorporates two unions, one at either end, to facilitate reversal for convergent or divergent testing. A probe is provided to measure the total pressure head along the test section by positioning it at any section of the duct. This probe may be moved after slackening the gland nut, which should be re-tightened by hand. To prevent damage, the probe should be fully inserted during transport/storage. The pressure tappings are connected to manometers that are mounted on a baseboard. The flow through the test section can be adjusted by the apparatus control valve or the bench control valve.



Manometer No.	Test section diameter (mm)
h1	25.0
h2	13.9
h3	11.8
h4	10.7
h5	10.0
h6	25.0

Figure 7-2: Schematic of Venturi Tube

7.7 THEORY

Bernoulli's theorem assumes that the flow is frictionless, steady, and incompressible. These assumptions are also based on the laws of conservation of mass and energy. Thus, the input mass and energy for a given control volume are equal to the output mass and energy:

$$Q_{in} = Q_{out}$$ **Equation 7-1**

$$E_{\text{in}} = E_{\text{out}}$$ **Equation 7-2**

These two laws and the definition of work and pressure are the basis for Bernoulli's theorem and can be expressed as follows for any two points located on the same streamline in the flow

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$ **Equation 7-3**

where:

p: pressure,

g: acceleration due to gravity,

v: fluid velocity, and

z: vertical elevation of the fluid.

In this experiment, since the duct is horizontal, the difference in height can be disregarded, i.e., $z_1=z_2$

The hydrostatic pressure (P) along the flow is measured by manometers tapped into the duct. The pressure head (h), thus, is calculated as:

$$h = \frac{p}{\rho g}$$ **Equation 7-4**

Therefore, Bernoulli's equation for the test section can be written as:

$$h_1 + \frac{v_1^2}{2g} = h_2 + \frac{v_2^2}{2g}$$ **Equation 7-5**

in which $\frac{v_2^2}{2g}$ is called the velocity head (h_d).

The total head (h_t) may be measured by the traversing hypodermic probe. This probe is inserted into the duct with its end-hole facing the flow so that the flow becomes stagnant locally at this end; thus:

$$h_t = h + \frac{v^2}{2g}$$ **Equation 7-6**

The conservation of energy or the Bernoulli's equation can be expressed as:

$$h_{t_1} = h_{t_2}$$ **Equation 7-7**

The flow velocity is measured by collecting a volume of the fluid (V) over a time period (t). The flow rate is calculated as:

$$Q = \frac{V}{t}$$ **Equation 7-8**

The velocity of flow at any section of the duct with a cross-sectional area of A is determined as:

$$v = \frac{Q}{A}$$ **Equation 7-9**

For an incompressible fluid, conservation of mass through the test section should be also satisfied (Equation 1a), i.e.:

$$A_1 v_1 = A_2 v_2$$ **Equation 7-10**

7.8 EXPERIMENTAL PROCEDURE

1. Place the apparatus on the hydraulics bench, and ensure that the outflow tube is positioned above the volumetric tank to facilitate timed volume collections.
2. Level the apparatus base by adjusting its feet. (A sprit level is attached to the base for this purpose.) For accurate height measurement from the manometers, the apparatus must be horizontal.
3. Install the test section with the 14° tapered section converging in the flow direction. If the test section needs to be reversed, the total head probe must be retracted before releasing the mounting couplings.
4. Connect the apparatus inlet to the bench flow supply, close the bench valve and the apparatus flow control valve, and start the pump. Gradually open the bench valve to fill the test section with water.
5. The following steps should be taken to purge air from the pressure tapping points and manometers:
    a. Close both the bench valve and the apparatus flow control valve.
    b. Remove the cap from the air valve, connect a small tube from the air valve to the volumetric tank, and open the air bleed screw.
    c. Open the bench valve and allow flow through the manometers to purge all air from them, then tighten the air bleed screw and partly open the bench valve and the apparatus flow control valve.
    d. Open the air bleed screw slightly to allow air to enter the top of the manometers (you may need to adjust both valves to achieve this), and re-tighten the screw when the

manometer levels reach a convenient height. The maximum flow will be determined by having a maximum (h1) and minimum (h5) manometer readings on the baseboard.

e. If needed, the manometer levels can be adjusted by using an air pump to pressurize them. This can be accomplished by attaching the hand pump tube to the air bleed valve, opening the screw, and pumping air into the manometers. Close the screw, after pumping, to retain the pressure in the system.

6. Take readings of manometers h_1 to h_6 when the water level in the manometers is steady. The total pressure probe should be retracted from the test section during this reading.
7. Measure the total head by traversing the total pressure probe along the test section from h1 to h_6.
8. Measure the flow rate by a timed volume collection. To do that, close the ball valve and use a stopwatch to measure the time it takes to accumulate a known volume of fluid in the tank, which is read from the sight glass. You should collect fluid for at least one minute to minimize timing errors. You may repeat the flow measurement twice to check for repeatability. Be sure that the total pressure probe is retracted from the test section during this measurement.
9. Reduce the flow rate to give the head difference of about 50 mm between manometers 1 and 5 (h_1-h_5). This is the minimum flow experiment. Measure the pressure head, total head, and flow.
10. Repeat the process for one more flow rate, with the (h_1-h_5) difference approximately halfway between those obtained for the minimum and maximum flows. This is the average flow experiment.
11. Reverse the test section (with the 21° tapered section converging in the flow direction) in order to observe the effects of a more rapidly converging section. Ensure that the total pressure probe is fully withdrawn from the test section, but not pulled out of its guide in the downstream coupling. Unscrew the two couplings, remove the test section and reverse it, then re-assemble it by tightening the couplings.
12. Perform three sets of flow, and conduct pressure and flow measurements as above.

7.9 RESULTS AND CALCULATIONS

Please visit this link for accessing excel workbook for this experiment.

7.9.1 RESULTS

Enter the test results into the Raw Data Tables.

Position 1: Tapering 14° to 21°				
Test Section	Volume (Litre)	Time (sec)	Pressure Head (mm)	Total Head (mm)
h_1				
h_2				
h_3				
h_4				
h_5				
h_6				
h_1				
h_2				
h_3				
h_4				
h_5				
h_6				
h_1				
h_2				
h_3				
h_4				
h_5				
h_6				

Position 2: Tapering 21° to 14°				
Test Section	Volume (Litre)	Time (sec)	Pressure Head (mm)	Total Head (mm)
h_1				
h_2				
h_3				
h_4				
h_5				
h_6				
h_1				
h_2				
h_3				
h_4				
h_5				
h_6				
h_1				
h_2				
h_3				
h_4				
h_5				
h_6				

7.9.2 CALCULATIONS

For each set of measurements, calculate the flow rate; flow velocity, velocity head, and total head, (pressure head+ velocity head). Record your calculations in the Result Table.

Position 1: Tapering 14° to 21°									
Test No.	Test Section	Distance into duct (m)	Flow Area (m^2)	Flow Rate (m^3/s)	Velocity (m/s)	Pressure Head (m)	Velocity Head (m)	Calculated Total Head (m)	Measured Total Head (m)
1	h1	0	0.00049						
	h2	0.06028	0.00015						
	h3	0.06868	0.00011						
	h4	0.07318	0.00009						
	h5	0.08108	0.000079						
	h6	0.14154	0.00049						
2	h1	0	0.00049						
	h2	0.06028	0.00015						
	h3	0.06868	0.00011						
	h4	0.07318	0.00009						
	h5	0.08108	0.000079						
	h6	0.14154	0.00049						
3	h1	0	0.00049						
	h2	0.06028	0.00015						
	h3	0.06868	0.00011						
	h4	0.07318	0.00009						
	h5	0.08108	0.000079						
	h6	0.14154	0.00049						

Position 2: Tapering 21° to 14°									
Test No.	Test Section	Distance into duct (m)	Flow Area (m^2)	Flow Rate (m^3/s)	Velocity (m/s)	Pressure Head (m)	Velocity Head (m)	Calculated Total Head (m)	Measured Total Head (m)
1	h1	0	0.00049						
	h2	0.06028	0.00015						
	h3	0.06868	0.00011						
	h4	0.07318	0.00009						
	h5	0.08108	0.000079						
	h6	0.14154	0.00049						
2	h1	0	0.00049						
	h2	0.06028	0.00015						
	h3	0.06868	0.00011						
	h4	0.07318	0.00009						
	h5	0.08108	0.000079						
	h6	0.14154	0.00049						
3	h1	0	0.00049						
	h2	0.06028	0.00015						
	h3	0.06868	0.00011						
	h4	0.07318	0.00009						
	h5	0.08108	0.000079						
	h6	0.14154	0.00049						

7.10 REPORT

Use the template provided to prepare your lab report for this experiment. Your report should include the following:

i.) Table(s) of raw data

ii.) Table(s) of results

iii.) For each test, plot the total head (calculated and measured), pressure head, and velocity head (y-axis) vs. distance into duct (x-axis) from manometer 1 to 6, a total of six graphs. Connect the data points to observe the trend in each graph. Note that the flow direction in duct Position 1 is from manometer 1 to 6; in Position 2, it is from manometer 6 to 1.

iv.) Comment on the validity of Bernoulli's equation when the flow converges and diverges along the duct.

v.) Comment on the comparison of the calculated and measured total heads in this experiment.

vi.) Discuss your results, referring, in particular, to the following:

a. energy loss and how it is shown by the results of this experiment, and

b. the components of Bernoulli's equation $\left(\frac{P}{\rho g}, \frac{v^2}{2g}, z\right)$ and how they vary along the length of the test section. Indicate the points of maximum velocity and minimum pressure.

8 TO INVESTIGATE THE VALIDITY OF THEORITICAL EXPRESSION FOR THE FORCE GIVEN BY A JET ON TARGETS OF VARIOUS SHAPES

8.1 INTRODUCTION

Moving fluid, in natural or artificial systems, may exert forces on objects in contact with it. To analyze fluid motion, a finite region of the fluid (control volume) is usually selected, and the gross effects of the flow, such as its force or torque on an object, is determined by calculating the net mass rate that flows into and out of the control volume. These forces can be determined, as in solid mechanics, by the use of Newton's second law, or by the momentum equation. The force exerted by a jet of fluid on a flat or curve surface can be resolved by applying the momentum equation. The study of these forces is essential to the study of fluid mechanics and hydraulic machinery.

8.2 PRACTICAL APPLICATION

Engineers and designers use the momentum equation to accurately calculate the force that moving fluid may exert on a solid body. For example, in hydropower plants, turbines are utilized to generate electricity. Turbines rotate due to force exerted by one or more water jets that are directed tangentially onto the turbine's vanes or buckets. The impact of the water on the vanes generates a torque on the wheel, causing it to rotate and to generate electricity.

8.3 OBJECTIVE

The objective of this experiment is to investigate the reaction forces produced by the change in momentum of a fluid flow when a jet of water strikes a flat plate or a curved surface, and to compare the results from this experiment with the computed forces by applying the momentum equation.

8.4 METHOD

The momentum force is determined by measuring the forces produced by a jet of water impinging on solid flat and curved surfaces, which deflect the jet at different angles.

8.5 EQUIPMENT

The following equipment is required to perform the impact of the jet experiment:

- F1-10 hydraulics bench,
- F1-16 impacts of a jet apparatus with three flow deflectors with deflection angles of 90, 120, and 180 degrees, and Stopwatch for timing the flow measurement.

8.6 EQUIPMENT DESCRIPTION

The jet apparatus is a clear acrylic cylinder, a nozzle, and a flow deflector (Figure 5.1). Water enters vertically from the top of the cylinder, through a nozzle striking a target, mounted on a stem, and leaves through the outlet holes in the base of the cylinder. An air vent at the top of the cylinder maintains the atmospheric pressure inside the cylinder. A weight pan is mounted at the top of the stem to allow the force of the striking water to be counterbalanced by applied masses [5].

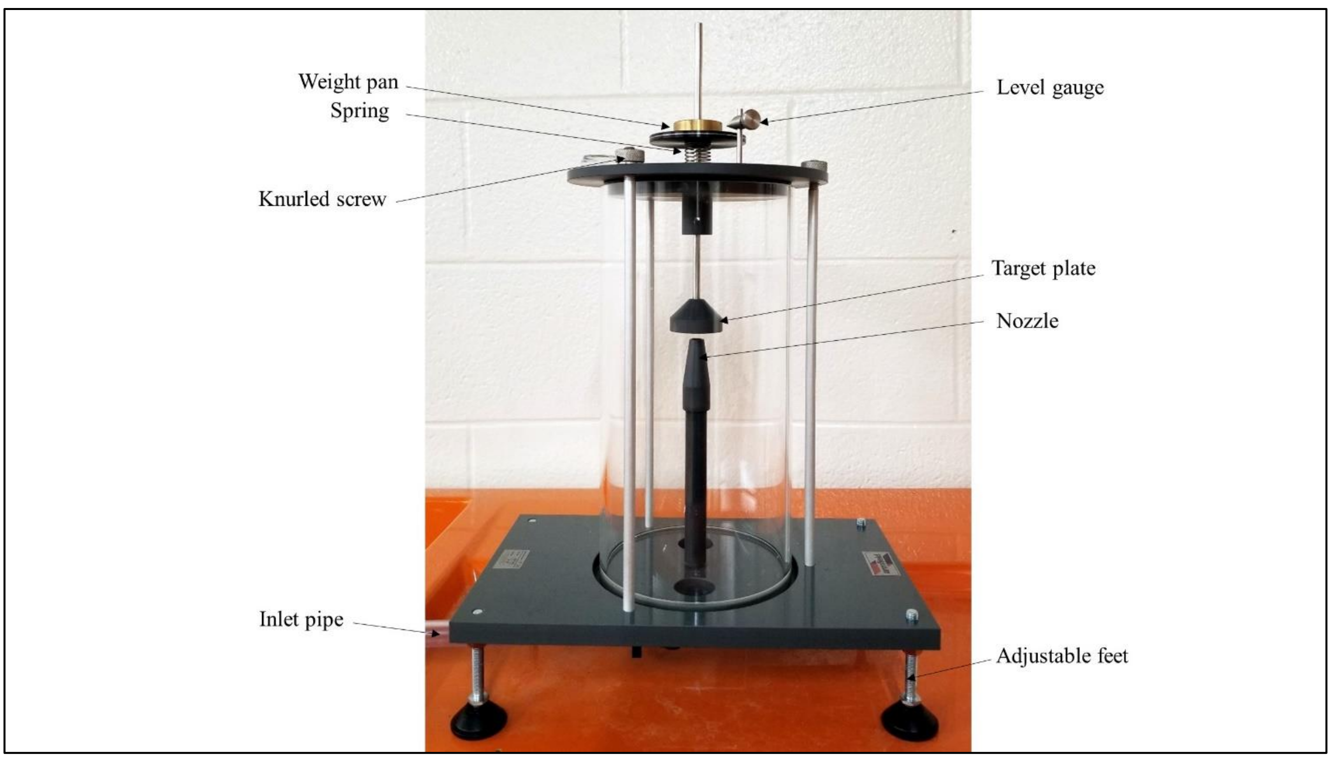


Figure 8-1: Impact of Jet Apparatus

8.7 THEORY

The velocity of the water (v) leaving the nozzle with the cross-sectional area (A) can be calculated by:

$$v = \frac{Q}{A}$$ **Equation 8-1**

in which Q is the flow rate.

Applying the energy equation between the nozzle exit point and the surface of the deflector shows that the magnitude of the flow velocity does not change as the water flows around the deflector; only the direction of the flow changes.

Applying the momentum equation to a control volume encompassing the deflected flow results in:

$$F_y = \rho Q v(cos\theta + 1)$$ **Equation 8-2**

where:

F_y force exerted by the deflector on the fluid

ρ : fluid density

$\theta : 180 - \alpha$, where α is the flow deflection angle (Figure 5.2).

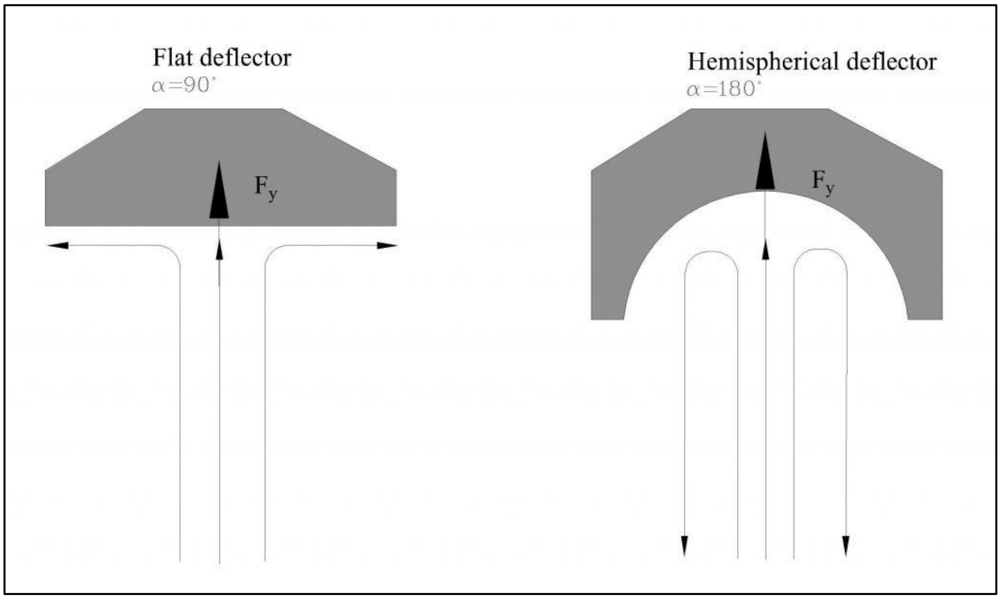


Figure 8-2: Schematic of Impact of Jet

From equilibrium of forces in a vertical direction, Fy is balanced by the applied weight on the weight pan, W (W = mg, where m is the applied mass), i.e., Fy = W. Therefore:

$$W = \rho Q v(cos\theta + 1) \qquad \textbf{Equation 8-3}$$

Since Q = vA, this equation can be written as:

$$W = \rho A v^2 (cos\theta + 1) \qquad \textbf{Equation 8-4}$$

8.8 EXPERIMENTAL PROCEDURE

Perform the experiment by taking the following steps:

1. Remove the top plate (by releasing the knurled nuts) and the transparent cylinder from the equipment, and check and record the exit diameter of the nozzle.
2. Replace the cylinder, and screw the 90-degree deflector onto the end of the shaft.
3. Connect the inlet tube to the quick-release connector on the bench.
4. Replace the top plate on the transparent cylinder, but do not tighten the three knurled nuts.
5. Using the spirit level attached to the top plate, level the cylinder by adjusting the feet.

6. Replace the three knurled nuts, then tighten in sequence until the built-in circular spirit level indicates that the top plate is horizontal. Do not overtighten the knurled nuts, as this will damage the top plate. The nuts should only be tightened enough to level the plate.
7. Ensure that the vertical shaft is free to move and is supported by the spring beneath the weight pan.
8. With no weights on the weight pan, adjust the height of the level gauge until it aligns with the datum line on the weight pan. Check that the position is correct by gently oscillating the pan.
9. Place a mass of 50 grams on the weight pan, and turn on the pump.
10. Open the bench valve slowly, and allow water to impinge upon the target until the datum line on the weight pan is level with the gauge. Leave the flow constant. Observe and note the flow behavior during the test.
11. Measure the flow rate, using the volumetric tank. This is achieved by closing the ball valve and measuring the time that it takes to accumulate a known volume of fluid in the tank, as measured from the sight glass. You should collect water for at least one minute to minimize timing errors.
12. Repeat this procedure by adding an additional 50 grams incrementally, until a maximum mass of 500 grams has been applied.
13. Repeat the entire test for each of the other two flow deflectors.

8.9 RESULTS AND CALCULATIONS

8.9.1 RESULTS

Use the following tables to record your measurements.

Test No.	Deflection Angles (degree)								
	90			120			180		
	Volume (Liter)	Time (s)	Applied Mass (kg)	Volume (Liter)	Time (s)	Applied Mass (kg)	Volume (Liter)	Time (s)	Applied Mass (kg)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

8.9.2 CALCULATIONS

The nozzle should be of the following dimensions.

Diameter of the nozzle: d= _
Cross sectional area of the nozzle: A= _
These values may be measured as part of the experimental procedure and replaced with the above dimensions.

For each set of measurements, calculate the applied weight (W), flow rate (Q), velocity squared (v^2), force (F_y), and theoretical and experimental slope (S) of the relationship between W and v^2. The theoretical slope is determined, as follows:

$$S = \rho A(cos\theta + 1)$$ **Equation 8-5**

The experimental value of S is obtained from a graph W of plotted against v^2.

Result Table

Nozzle Diameter (m)=				Flow Area (m^2) =		Deflector Angle (degree)=	
Test No.	Applied Weight (N)	Flow Rate (m^3/s)	Velocity (m/s)	Velocity^2 $(m/s)^2$	Force (N)	Theoretical Slope	Experimental Slope
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

8.10 REPORT

Use the template provided to prepare your lab report for this experiment. Your report should include the following:

i.) Table(s) of raw data

ii.) Table(s) of results

iii.) Graph(s)

iv.) Plot a graph of velocity squared, v^2, (x-axis) against applied weight, W, (y-axis). Prepare one graph, presenting the results for all three deflectors, and use a linear trend line, setting the intercepts to zero, to show this relationship. Find the slopes of these lines. Record the slopes in the Results Table, as the experimental slope.

v.) Compare the slopes of this graph with the slopes calculated from the theoretical relationship from Equation 8-5.

vi.) Plot the measured force from the weights (W) versus the force of the water on the deflector (F_y) that is calculated by using the momentum equation, i.e., Equation 8-2

vii.) Discuss your results, focusing on the following:

a. Does this experiment provide a feasible means of verifying the conservation of momentum equation? Try to be quantitative in your comparison between the experimental and calculated results.
b. Would the results have been different if the deflectors were closer to the nozzle? Explain.
c. Comment on the agreement between your theoretical and experimental results, and give reasons for any differences.
d. Comment on the significance of any experimental errors.

9 TO STUDY FLOW THROUGH CIRCULAR ORIFICES AND COEFFICIENT OF DISCHARGE, CONTRACTION AND VELOCITY

9.1 INTRODUCTION

An orifice is an opening which can be characterised by its shape or type of edge in the side or base of a tank or reservoir through which a fluid can be freely discharged or discharged in a submerged environment. True orifice flow occurs only when the upstream water level is well above the orifice to reduce vortex flow through air entrainment. If this level drops below the top of the opening, the discharge has to be considered as being through a weir (n.d.). A small orifice is one which has a diameter or vertical dimension much smaller than the head causing the flow so as there is negligible head between point to point along the orifice (Douglas et al). The figure below shows the orifice characteristics and true orifice flow.

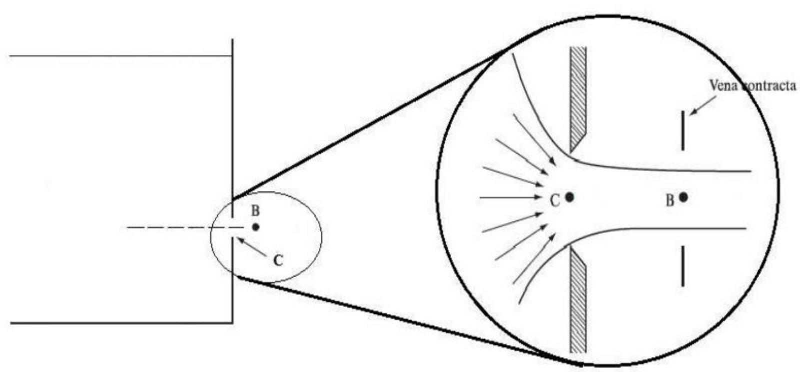


Figure 9-1: Schematic of Orifice

In this experiment, a tank having a circular orifice has been considered. The orifice has a sharp edge with the bevelled side facing outward. An orifice usually has a sharp edge so that the fluid has minimum contact with the fluid and reduced frictional resistance at the sides of the orifice. If sharp edges are not provided, the thickness of the orifice and its roughness together affect the flow. A free jet has been considered and as such it occurs in air and is acted upon by gravity. When a jet is surrounded with fluid, it is called a submerged jet. A submerged jet has no gravity acting upon it when the surrounding fluid is the same.

9.2 AIMS AND OBJECTIVES

The aims of the experiment were to determine for a circular sharp edged orifice:

- The coefficient of velocity,
- The coefficient of contraction,
- The coefficient of discharge

The objectives of the experiment were to:

- Maintain a constant head for each experiment
- Measure the x and y distances
- Measure the discharge

9.3 LITERATURE REVIEW

When the fluid flows from the upstream level to the orifice there is an increase in velocity and it will contract from all angles towards the orifice. Consequently the streamlines have a perpendicular velocity directed towards the centre of the orifice causing the emerging jet to contract resulting in it having a smaller diameter than the orifice it passed through. The contraction continues till its maximum at the vena contracta where all the streamlines are assumed to be horizontal (Spencer, 2013). Beyond the vena contracta, friction with the air (fluid) slows down the jet and the cross sectional area increases per force. However this divergence is negligible and the jet is considered as almost cylindrical with a constant velocity. The surface tension maintains the jet, which has a stronger effect the smaller the diameter of the jet. The figure below shows the observed jet during experiment.

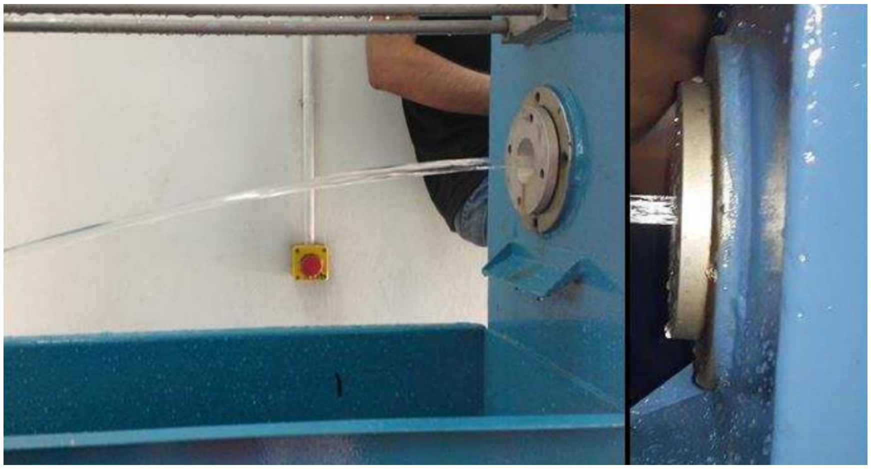


Figure 9-2: Flow of water through a circular Orifice

The figure below shows a tank with a small orifice in the side. Calculations are based by taking the datum at the centre of the orifice

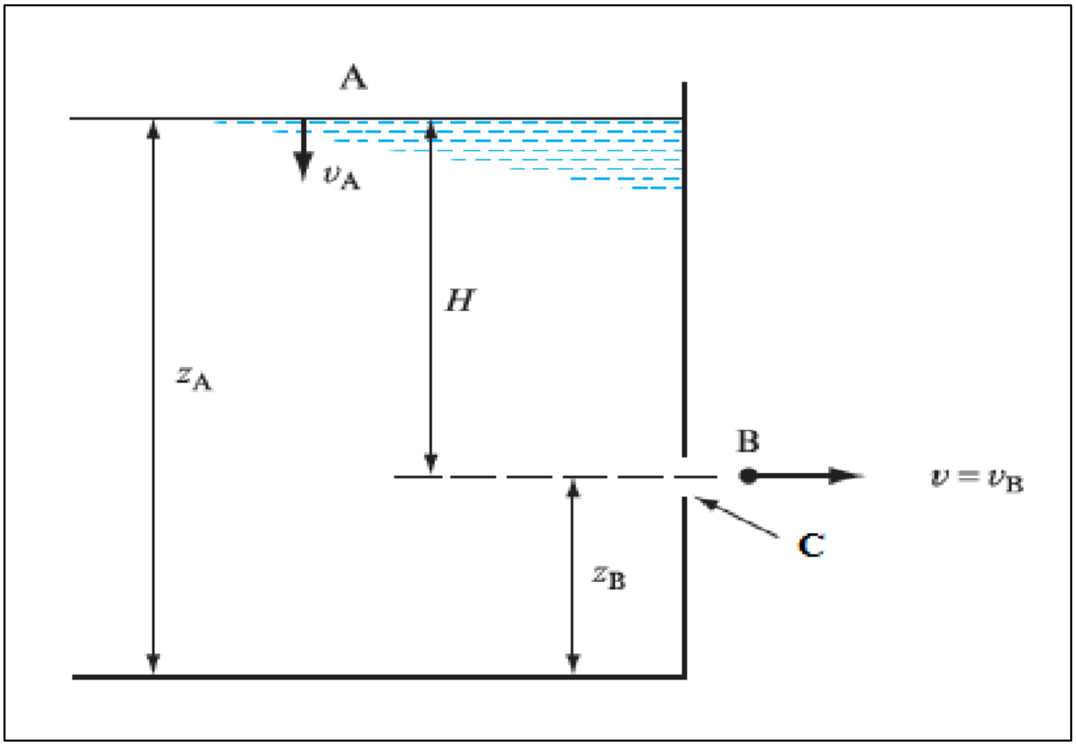


Figure 9-3: Schematic of Orifice Flow

Applying the principle of conservation of energy in the form of the Bernoulli's equation at A and B, the velocity at the vena contracta can be obtained. Full derivation of the equations can be found in appendix A.

$$\frac{p_A}{\rho g} + \frac{v_A^2}{2g} + z_A = \frac{p_B}{\rho g} + \frac{v_B^2}{2g} + z_B$$ **Equation 9-1**

$$v = \sqrt{2gH}$$ **Equation 9-2**

This is the Torricelli's theorem which states that the velocity of the issuing jet is proportional to the square root of the head. Due to energy losses, the coefficient of velocity is included in the equation and is found from theory as:

$$c_v = \frac{\text{velocity at vena contracta}}{\text{Theoretical velocity}} = \frac{V}{\sqrt{2gH}}$$ **Equation 9-3**

Since the actual velocity, V, cannot be accurately measured, an alternate solution is used. The figure below illustrates the method of calculating the coefficient of velocity used in the experiment.

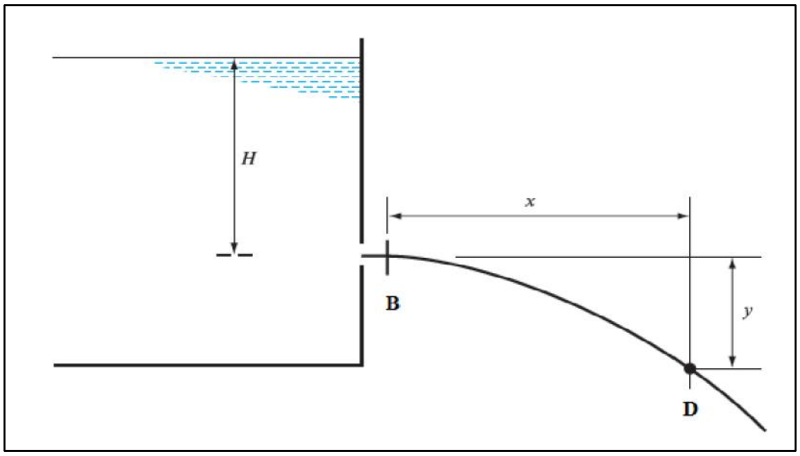


Figure 9-4: Parabola formation by Orifice Flow

$$x = vt;\ y = \frac{1}{2}gt^2;\ c_v = \frac{x}{\sqrt{4Hy}}$$ **Equation 9-4**

The coefficient of discharge is obtained from

$$c_d = \frac{\text{Actual discharge in } t \text{ seconds}}{\text{Theoretical discharge in } t \text{ seconds}} = \frac{Q}{A\sqrt{2gH}}$$ **Equation 9-5**

Where A is area of orifice

The coefficient of contraction is obtained from the equation

$$C_c = \frac{\text{Area of jet at vena contracta}}{\text{Actual area of orifice}} = \frac{C_d}{C_v}$$ **Equation 9-6**

It should be noted that practically, the area at the vena contracta cannot be measured as it cannot be accurately determined. Previous experiments have shown typical values for coefficient of velocity to be in the order of 0.96. For the coefficient of discharge it is in the order of 0.62 and for the coefficient of contraction it is about 0.64.

9.4 METHODOLOGY

9.4.1 EXPERIMENTAL APPARATUS

- Tank with an orifice in the side
- Channel canal
- Collector tank
- Stopwatch
- Vernier calliper
- Ruler

9.5 PROCEDURE

1) A constant head of H m was maintained above the centre line of the orifice by adjusting the flow from the water supply using the tap.
2) After reaching steady conditions the discharge from the orifice was collected over a convenient time measured using a stopwatch and the initial and final height, Z1 and Z2, during this time of the collected discharge in the discharge tank was noted.
3) The vertical fall, y, of the centre-line of the jet over a horizontal distance x was obtained by means of a hook gauge and scale.
4) The procedure was repeated for different heads H and the values tabulated.
5) The diameter of the orifice was measured by means of a Vernier calliper as shown below.

9.6 DATA COLLECTION AND ANALYSIS

Tank dimensions

Length =

Width =

Area =

Diameter of orifice = 12 mm

The equations below have been used to calculate the respective coefficients.

$$C_v = \frac{V}{\sqrt{2gH}}; C_d = \frac{Q}{A\sqrt{2gH}}; C_c = \frac{C_d}{C_v}$$ **Equation 9-7**

9.7 DISCUSSION

Typical values of coefficient of velocity, coefficient of discharge and coefficient of contraction include 0.96, 0.62 and 0.64 respectively. As it can be observed errors have been introduced within the experiment most of them systematic as the values although precise are not accurate. The experimental procedure has been observed to be flawed in the following respect.

10 TO DETERMINE THE CHARACTERSTICS OF FLOW OVER A V- NOTCH

10.1 INTRODUCTION

A weir is a barrier across the width of a river or stream that alters the characteristics of the flow and usually results in a change in the height of the water level. Several types of weirs are designed for application in natural channels and laboratory flumes. Weirs can be broad-crested, short-crested, or sharp-crested. Sharp-crested weirs, commonly referred to as *notches*, are manufactured from sharp-edged thin plates. The relationship between the flow rate and water depth above the weir can be derived by applying the Bernoulli's equation and by making some assumptions with regard to head loss and pressure distribution of the flow passing over the weir. A coefficient of discharge needs to be determined experimentally for each weir to account for errors in estimating the flow rate that is due to these assumptions.

10.2 PRACTICAL APPLICATION

Weirs are commonly used to measure or regulate flow in rivers, streams, irrigation canals, etc. Installing a weir in an open channel system causes critical depth to form over the weir. Since there is a unique relationship between the critical depth and discharge, a weir can be designed as a flow-measuring device. Weirs are also built to raise the water level in a channel to divert the flow to irrigation systems that are located at higher elevations.

10.3 OBJECTIVE

The objectives of this experiment are to:

a) determine the characteristics of flow over a rectangular and triangular weir, and

b) determine the value of the discharge coefficient for rectangular notches.

10.4 METHOD

The coefficients of discharge are determined by measuring the height of the water surface above the notch base and the corresponding flow rate. The general features of the flow can be determined by direct observation.

10.5 EQUIPMENT

The following equipment is required to perform the flow over weirs experiment:

- F1-10 hydraulics bench;
- F1-13 triangular weir;
- Vernier height gauge; and
- Stopwatch.

10.6 EQUIPMENT DESCRIPTION

The flow over the weir apparatus includes the following elements that are used in conjunction with the flow channel in the molded bench top of the hydraulics bench (Figure 10-1).

- A combination of a stilling baffle and the inlet nozzle to promote smooth flow conditions in the channel.
- A vernier hook and point gauge, mounted on an instrument carrier, to allow measurement of the depth of flow above the base of the notch.
- The weir notches that are mounted in a carrier at the outlet end of the flow channel.

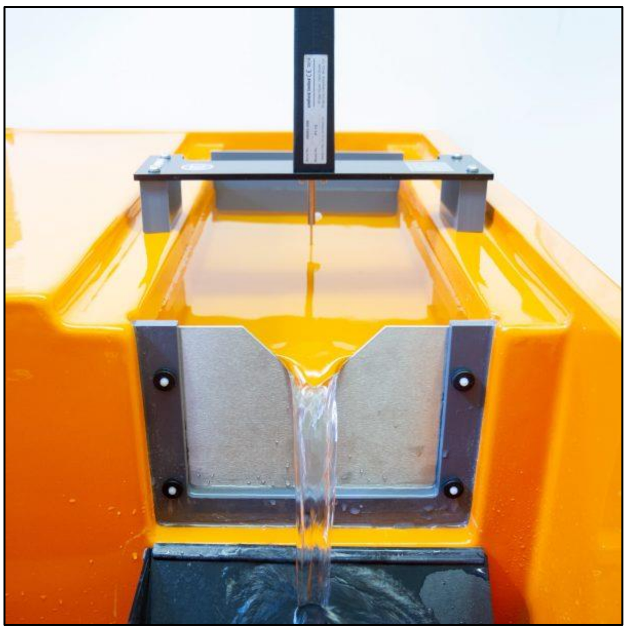


Figure 10-1: Hydraulics bench and weir apparatus

10.7 THEORY

The depth of water above the base of a weir is related to the flow rate through it; therefore, the weir can be used as a flow measuring device. The relationships of flow over weirs can be obtained by applying the energy equation from a point well upstream of the weir to a point just above the weir crest. This approach requires a number of assumptions, and it yields the following results:

- for a triangular weir (Figure 10-2):

$$C_d \frac{8}{15}\sqrt{2g}\tan\frac{\theta}{2}H^{\frac{5}{2}}$$ **Equation 10-1**

where:

Q: flow rate;

H: height above the weir base;

θ : angle of triangular weir (V-notch);

C_d: discharge coefficient to account for the effects of simplifying assumptions in the theory, which has to be determined by experiment [9].

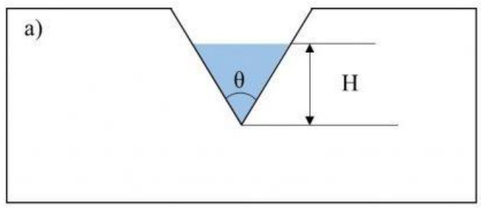


Figure 10-2: Triangular weir

- for a V-notch

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

10.8 EXPERIMENTAL PROCEDURE

This experiment will be performed by taking the following steps:

- Ensure that the hydraulics bench is positioned so that its surface is horizontal. This is necessary because the flow over the notch is driven by gravity.
- Mount the triangular notch plate onto the flow channel, and position the stilling baffle as shown in Figure 9.3.
- Turn on the pump, and slightly adjust the flow control to fill the channel upstream of the weir with water.
- Turn off the pump when the water starts to flow over the weir.
- Wait a few minutes to allow the water to settle.
- Level the point gauge with the water level in the channel. Record the reading as ho.

Note: To measure the datum height of the base of the notch (ho), position the instrument carrier as shown in Figure 10-3. Then carefully lower the gauge until the point is just above the notch base, and lock the coarse adjustment screw. Then, using the fine adjustment, adjust the gauge until the point just touches the water surface and take a reading, being careful not to damage the notch.

- Adjust the point gauge to read 10 mm greater than the datum.
- Record the reading as h.
- Turn on the pump, and slightly adjust the flow until the water level coincides with the point gauge. Check that the level has stabilized before taking readings.
- Measure the flow rate using the volumetric tank.
- Observe the shape of the nappe and take pictures of it.

Note*:* The surface of the water will fall as it approaches the weir. This is particularly noticeable at high flow rates by high heads. To obtain an accurate measurement of the undisturbed water level above the crest of the weir, it is necessary to place the measuring gauge at a distance of at least three times the head above the weir.

- Increase the flow by opening the bench regulating valve to set the heads above the datum level in 10 mm increments until the regulating valve is fully open. Take care not to allow spillage to occur over the plate top that is adjacent to the notch. At each condition, measure the flow rate and observe the shape of the nappe.

Note: To obtain a sufficiently accurate result, collect around 25 liters of water each time, or collect the water for at least 120 seconds.

- Close the regulating valve, stop the pump, and then replace the weir with the V-notch.
- Repeat the experiment with the V-notch weir plate, but with 5 mm increments in water surface elevation.
- Collect seven head and discharge readings for each weir.

Figure 10-3: Position of the notch and Vernier height gauge to set the datum.

10.9 RESULTS AND CALCULATIONS

10.9.1 RESULT

Use the following tables to record your measurements. Record any observations of the shape and the type of 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 9.4 to classify the nappe).

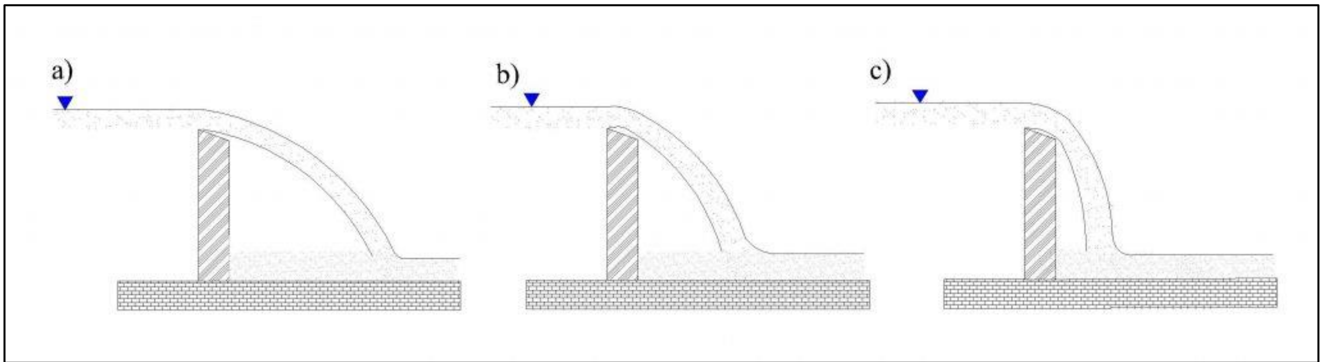


Figure 10-4: Types of nappe: a) Springing clear nappe, b) Depressed Nappe, and c) Clinging Nappe

Raw Data Table: V-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				
6				
7				

10.10 CALCULATIONS

- The following dimensions from the equipment can be used in the appropriate calculations:
  - angle of V-notch (θ) = 90°
- Calculate discharge (Q) and head (h) for each experiment, and record them in the Result 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., $H = h\text{-}h_o$
- Calculate $H^{5/}$for the triangular notch.
- For each measurement, calculate the experimental values of C_d for the triangular notch, using Equation 10-14, respectively.
- Record your calculations in the Results Tables.

Result Table: V-notch

No.	H (m)	Volume Collected (m3)	Flow Rate (m3/s)	$H^{5/2}$	Experimental Cd	Theoretical Cd	%Error
1							
2							
3							
4							
5							
6							
7							

10.11 REPORT

- Use the template provided to prepare your lab report for this experiment. Your report should include the following:
- Table(s) of raw data
- Table(s) of results
- Graph(s)
  - Schematic drawings or photos of the nappes observed during each experiment, with an indication of their type.
  - Plot a graph of 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 and in the form of: $Q = mH^n$ in which the exponent value n is 2.5 for the triangular weir. Calculate the coefficients of discharge C_d (theoretical method). Record C_d values calculated from the theoretical

method in the Result Tables.

for a triangular notch:

$$C_d = \frac{m}{\frac{8}{15}\sqrt{2g}\tan\left(\theta/2\right)}$$

- Compare the experimental results to the theory by calculating the percentage of error.
- What are the limitations of the theory?
- Why would you expect wider variation of C_d values at lower flow rates?
- Compare the results for C_d of the weirs utilized in this experiment with those you may find in a reliable source (e.g., textbooks). Include in your report a copy of the tables or graphs you have used for textbook values of C_d.
- Discuss your observations and any source of errors in calculation of C_d.

11 DETERMINATION OF CALIBRATION CURVE FOR A STANDING WAVE FLUIME

11.1 Aim

- To determine the coefficient of discharge (C_j) for a given standing wave flume both by calculation and graphically.
- To calibrate the standing wave flume by preparing a calibration curve for it.

11.2 Introduction:

Venturi flume is an artificial construction provided in a channel for the purpose of measuring the discharge passing through it. Venturi flume is similar to a venturimeter which is used for measuring the discharge passing through a pipe. The formula for the discharge passing through the venturi flume can be derived exactly in the same manner and as it was derived for the venturimeter i.e. by applying Bernoulli's equation along with the continuity equation.

When the flow through the venturi flume occurs under critical condition (i.e. when the specific energy is minimum for a given discharge or discharge is maximum for a given specific energy.) then a hydraulic jump or standing wave flume is formed on the downstream side of the diverging portion of the venturi flume under the favorable conditions. The venturi-flume is then called as 'Standing wave flume' or 'Critical Depth flume'. Provision of a hump in the throat portion of the venturi flume ensures the formation of hydraulic jump over a wide range of discharge variation, so that the venturi flume essentially functions as a standing wave flume. The advantage of the standing wave flume is that the discharge can be obtained by measuring the depth of flow in the channel only at the upstream side.

Theory: Formula for discharge in ease of a venturi flume can be obtained by applying Bernoulli's equation along with

$$y_1+\frac{V_1^2}{2g}=y_2+\frac{V_2^2}{2g}\Rightarrow\left(y_1-y_2\right)=\frac{V_2^2}{2g}-\frac{V_1^2}{2g}$$ Equation 11-1

$$a_1V_1=a_2V_2\Rightarrow V_1=\frac{a_2}{a_1\times V_2}$$ Equation 11-2

$$y_1-y_2=\frac{V_2^2}{2g}-\frac{\left(\frac{a_2}{a_1\times V_2}\right)^2}{2g}\Rightarrow y_1-y_2=\frac{V_2^2}{2g}\left(1-\left(\frac{a_2}{a_1}\right)^2\right)$$ Equation 11-3

$$V_2=\frac{a_1\sqrt{2g\left(y_1-y_2\right)}}{\sqrt{a_1^2-a_2^2}}$$

$$Q=a_1\times V_2\Rightarrow Q=\frac{a_1a_2\sqrt{2g\left(y_1-y_2\right)}}{\sqrt{a_1^2-a_2^2}}$$ Equation 11-4

$$y_1+\frac{V_1^2}{2g}=\Delta z+y_2+\frac{V_2^2}{2g}=E$$ Equation 11-5

$$\frac{V_2^2}{2g}=E-y_2\Rightarrow V_2=\sqrt{2g\left(E-y_2\right)}$$ Equation 11-6

$$Q=by_2\sqrt{2g\left(E-y_2\right)}=b\sqrt{2g\left(Ey_2^2-y_2^3\right)}$$ Equation 11-7

For $Q_{\max}$

$$\frac{\partial Q}{\partial y_2}=0\Rightarrow\frac{\partial Q}{\partial y_2}=\frac{b\sqrt{2g}\,y_2\left(2Ey_2-4y_2^2\right)^{1/2}}{\sqrt{Ey^2-y_2^3}}$$ Equation 11-8

$$2Ey_2-3y_2^2=0\Rightarrow 2E\frac{y}{2}=3y_2\Rightarrow y=\frac{2}{3}E$$

$$v_2=\sqrt{2g}\left(\frac{3}{2}y_2-y_2\right)\Rightarrow v_2=\sqrt{2g\frac{y_2}{2}}$$ Equation 11-9

$$v_2=\sqrt{gy_2}$$

$$\frac{v_2}{\sqrt{gy_2}}=1\quad(\mathrm{Fr}=1)$$ Equation 11-10

$$Q_{\max} = b\sqrt{2g\left(E \times \frac{2}{3}E\right)^2 - \left(\frac{2}{3}E\right)^3} \qquad \text{Equation 11-11}$$

$$Q_{\max} = 1.705 \times b \times E^{3/2}$$

Experimental set up: It consists of glass walled (Perspex sheet made) rectangular tilting bed flume 5m long, 10.3 cm wide and 60 cm deep into which water is supplied by a pump. A sluice is fitted in the upstream side of the flume. A pointer gauge is used to measure the depth of water in the channel.

11.3 Procedure:-

1) Set up the tilting flume to zero bed slopes.
2) Obtain bed reading of flume at a section just on the u/s by installing pointer gauge.
3) Switch on the centrifugal pump and allow all discharge to pass through the flume by closing the valve.
4) Ensure the formation of standing wave i.e. hydraulic jump on D/s as standing wave flume.
5) Measure the depth of flow in flume by taking the water surface reading at D/s section with pointer gauge.
6) Measure the discharge passing through the flume with the help of measuring tank of the flume.
7) Repeat steps 5 and 6 for sufficient no. of observations.

Experimental data:

1. Width of tilting flume = T =
2. Width of throat of standing wave flume = B =
3. Height of hump of standing wave flume = z =
4. Bed slope of tilting flume = So =
5. Bed Reading of tilting flume (Initial Pointer gauge reading) = hi =
6. Area of the tank (Ai) =

11.4 Observation table:-

Sr. No.	Final pointer gauge Reading (FPGR) ‘h_2’ (cm)	Height of water collected in tank ‘h’ (cm)	Time to collect water in tank ‘t’ (sec.)
1.			
2.			
3.			
4.			
5.			

Calculation table: -

Sr. No.	Depth of flow at D/s ‘Y_1’ (m)	Actual Discharge ‘Q_{act}’ (m^3/sec)	Velocity ‘V’ (m/sec)	Specific Energy ‘E’ (m)	Theoretical Discharge ‘Q_{th}’ (m^3/sec)	Coefficient of Discharge ‘C_d’
1.						
2.						
3.						
4.						
5.						

Formulae

1. IPGR = h_1
2. Depth of flow at c/s= Y_1= FPGR- IPGR = $h_2 - h_1$ =
3. Actual Discharge = $Q_{act} = \frac{A_1 \times h}{t \times 1000}$
4. Velocity of flow= $V = \frac{Q_{act.}}{A} = \frac{Q_{act.}}{(B \times Y_1)}$
5. Specific Energy = $E = y_1 + \frac{V1^2}{2g}$
6. Theoretical Discharge = $Q_{th} = 1.7053 \times B \times E^{3/2}$
7. Coefficient of Discharge = $C_d = \frac{Qact}{Qth}$

12 DETERMINE THE LOSS COEFFICIENTS FOR VARIOUS BENDS AND FITTINGS

12.1 INTRODUCTION

Two types of energy loss predominate in fluid flow through a pipe network; major losses, and minor losses. Major losses are associated with frictional energy loss that is caused by the viscous effects of the medium and roughness of the pipe wall. Minor losses, on the other hand, are due to pipe fittings, changes in the flow direction, and changes in the flow area. Due to the complexity of the piping system and the number of fittings that are used, the head loss coefficient (K) is empirically derived as a quick means of calculating the minor head losses.

12.2 PRACTICAL APPLICATION

The term “minor losses”, used in many textbooks for head loss across fittings, can be misleading since these losses can be a large fraction of the total loss in a pipe system. In fact, in a pipe system with many fittings and valves, the minor losses can be greater than the major (friction) losses. Thus, an accurate K value for all fittings and valves in a pipe system is necessary to predict the actual head loss across the pipe system. K values assist engineers in totaling all of the minor losses by multiplying the sum of the K values by the velocity head to quickly determine the total head loss due to all fittings. Knowing the K value for each fitting enables engineers to use the proper fitting when designing an efficient piping system that can minimize the head loss and maximize the flow rate.

12.3 OBJECTIVE

The objective of this experiment is to determine the loss coefficient (K) for a range of pipe fittings, including several bends, a contraction, an enlargement, and a gate valve.

12.4 METHOD

The head loss coefficients are determined by measuring the pressure head differences across a number of fittings that are connected in series, over a range of steady flows, and applying the energy equation between the sections before and after each fitting.

12.5 EQUIPMENT

The following equipment is required to perform the energy loss in pipe fittings experiment:

- F1-10 hydraulics bench,
- F1-22 Energy losses in bends apparatus,
- Stopwatch for timing the flow measurement,
- Clamps for pressure tapping connection tubes,
- Spirit level, and
- Thermometer.

12.6 EQUIPMENT DESCRIPTION

The energy loss in fittings apparatus consists of a series of fittings, a flow control valve, twelve manometers, a differential pressure gauge, and an air-bleed valve (Figure 3.1).

The fittings listed below, connected in a series configuration, will be examined for their head loss coefficient (K):

- long bend,
- area enlargement,
- area contraction,
- elbow,
- short bend,
- gate valve, and
- mitre.

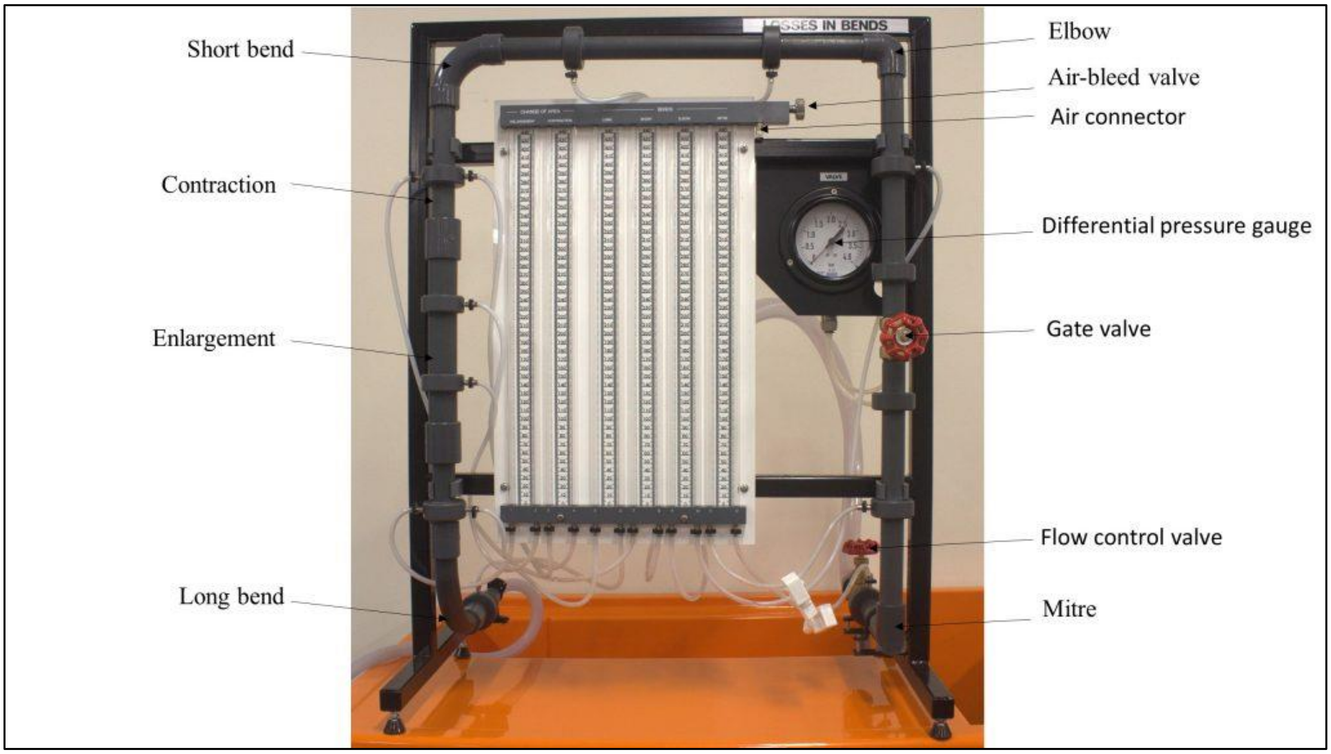


Figure 12-1: minor Losses in Pipe Apparatus

The manometers are tapped into the pipe system (one before and one after each fitting, except for the gate valve) to measure the pressure head difference caused by each fitting. The pressure difference for the valve is directly measured by the differential pressure gauge. The air-bleed valve facilitates purging the system and adjusting the water level in the manometers to a convenient level, by allowing air to enter them. Two clamps, which close off the tappings to the mitre, are introduced while experiments are being performed on the gate valve. The flow rate is controlled by the flow control valve.

The internal diameter of the pipe and all fittings, except for the enlargement and contraction, is 0.0183 m. The internal diameter of the pipe at the enlargement's outlet and the contraction's inlet is 0.0240 m.

12.7 THEORY

Bernoulli's equation can be used to evaluate the energy loss in a pipe system:

$$\left[\frac{P}{\gamma}+\frac{v^2}{2g}+z\right]_{in}=\left[\frac{P}{\gamma}+\frac{v^2}{2g}+z\right]_{out}+h_L$$

Equation 12-1

In this equation $\frac{P}{\gamma}, \frac{v^2}{2g}$, and z are pressure head, velocity head, and potential head, respectively. The total head loss, h_L, includes both major and minor losses.

If the diameter through the pipe fitting is kept constant, then $v_{in} = v_{out}$. Therefore, if the change in elevation head is neglected, the manometric head difference is the static head difference that is equal to the minor loss Δh through the fitting.

$$\left[\frac{P}{\gamma}\right]_{in} - \left[\frac{P}{\gamma}\right]_{out} = H_1 - H_2 = \Delta h$$ **Equation 12-2**

in which H_1 and H_2 are manometer readings before and after the fitting.

The energy loss that occurs in a pipe fitting can also be expressed as a fraction (K) of the velocity head through the fitting:

$$\Delta h = K \frac{v^2}{2g}$$ **Equation 12-3**

where:

K: loss coefficient, and

v: mean flow velocity into the fitting.

Because of the complexity of the flow in many fittings, K is usually determined by experiment [3]. The head loss coefficient (K) is calculated as the ratio of the manometric head difference between the input and output of the fitting to the velocity head.

$$K = \frac{\Delta h}{\frac{v^2}{2g}}$$ **Equation 12-4**

Due to the change in the pipe cross-sectional area in enlargement and contraction fittings, the velocity difference cannot be neglected. Thus:

$$(H_1 - H_2) + \left(\left[\frac{v^2}{2g} \right]_{in} - \left[\frac{v^2}{2g} \right]_{out} \right) = \Delta h$$ **Equation 12-5**

Therefore, these types of fittings experience an additional change in static pressure, i.e.:

$$\left(\left[\frac{v^2}{2g} \right]_{in} - \left[\frac{v^2}{2g} \right]_{out} \right)$$ **Equation 12-6**

This value will be negative for the contraction since $v_{in} > v_{out}$ and it will be positive for enlargement because $v_{in} < v_{out}$. From Equation (5), note that Δh will be negative for the enlargement.

The pressure difference (Δh) between before and after the gate valve is measured directly using the pressure gauge. This can then be converted to an equivalent head loss by using the conversion ratio:

1 bar= 10.2 m water

The loss coefficient for the gate valve may then be calculated by using Equation (4).

To identify the flow regime through the fitting, the Reynolds number is calculated as:

$$Re = \frac{vD}{\nu}$$ **Equation 12-7**

where v is the cross-sectional mean velocity, D is the pipe diameter and ν is the fluid kinematic viscosity (Figure 3.2).

Temperature (degree C)	Kinematic viscosity v (m^2/s)	Temperature (degree C)	Kinematic viscosity v (m^2/s)
0	1.793E-06	25	8.930E-07
1	1.732E-06	26	8.760E-07
2	1.674E-06	27	8.540E-07
3	1.619E-06	28	8.360E-07
4	1.522E-06	29	8.180E-07
5	1.520E-06	30	8.020E-07
6	1.474E-06	31	7.850E-07
7	1.429E-06	32	7.690E-07
8	1.386E-06	33	7.530E-07
9	1.346E-06	34	7.380E-07
10	1.307E-06	35	7.240E-07
11	1.270E-06	36	7.110E-07
12	1.235E-06	37	6.970E-07
13	1.201E-06	38	6.840E-07
14	1.169E-06	39	6.710E-07
15	1.138E-06	40	6.580E-07
16	1.108E-06	45	6.020E-07
17	1.080E-06	50	5.540E-07
18	1.053E-06	55	5.110E-07
19	1.027E-06	60	4.760E-07
20	1.002E-06	65	4.430E-07
21	9.780E-07	70	4.130E-07
22	9.550E-07	75	3.860E-07
23	9.330E-07	80	3.630E-07
24	9.110E-07	85	3.420E-07

Figure 12-2: Variation of Kinematic Viscosity with Temperature

It is not possible to measure head due to all of the fittings simultaneously; therefore, it is necessary to run two separate experiments.

12.7.1PART A:

In this part, head losses caused by fittings, except for the gate valve, will be measured; therefore, this valve should be kept fully open throughout Part A. The following steps should be followed for this part:

1. Set up the apparatus on the hydraulics bench and ensure that its base is horizontal.
2. Connect the apparatus inlet to the bench flow supply, run the outlet extension tube to the volumetric tank, and secure it in place.
3. Open the bench valve, the gate valve, and the flow control valve, and start the pump to fill the pipe system and manometers with water. Ensure that the air-bleed valve is closed.
4. To purge air from the pipe system and manometers, connect a bore tubing from the air valve to the volumetric tank, remove the cap from the air valve, and open the air-bleed screw to allow flow through the manometers. Tighten the air-bleed screw when no air bubbles are observed in the manometers.
5. Set the flow rate at approximately 17 liters/minute. This can be achieved by several trials of timed volumetric flow measurements. For flow measurement, close the ball valve, and use a stopwatch to measure the time that it takes to accumulate a known volume of fluid in the tank, which is read from the hydraulics bench sight glass. Collect water for at least one minute to

minimize errors in the flow measurement.

6. Open the air-bleed screw slightly to allow air to enter the top of the manometers; re-tighten the screw when the manometer levels reach a convenient height. All of the manometer levels should be on scale at the maximum flow rate. These levels can be adjusted further by using the air-bleed screw and the hand pump. The air-bleed screw controls the air flow through the air valve, so when using the hand pump, the bleed screw must be open. To retain the hand pump pressure in the system, the screw must be closed after pumping [3].
7. Take height readings from all manometers after the levels are steady.
8. Repeat this procedure to give a total of at least five sets of measurements over a flow range of 8 – 17 liters per minute.
9. Measure the outflow water temperature at the lowest flow rate. This, together with Figure 3.2, is used to determine the Reynolds number.
10.

12.7.2 PART B:

In this experiment, the head loss across the gate valve will be measured by taking the following steps:

1. Clamp off the connecting tubes to the mitre bend pressure tappings to prevent air being drawn into the system.
2. Open the bench valve and set the flow at the maximum flow in Part A (i.e., 17 liter/min); fully open the gate valve and flow control valve.
3. Adjust the gate valve until 0.3 bar of head difference is achieved.
4. Determine the volumetric flow rate.
5. Repeat the experiment for 0.6 and 0.9 bars of pressure difference.

12.8 RESULTS AND CALCULATIONS

Please visit this link for accessing excel workbook for this experiment.

12.8.1 RESULTS

Record all of the manometer and pressure gauge readings, as well as the volumetric measurements, in the Raw Data Tables.

Part A – Head Loss Across Pipe Fittings

Test No. 1: Volume Collected (liters):		Time (s):
Fitting	**h_1 (m)**	**h_2 (m)**
Enlargement		
Contraction		
Long Bend		
Short Bend		
Elbow		
Mitre		
Test No. 2: Volume Collected (liters):		Time (s):
Enlargement		
Contraction		
Long Bend		
Short Bend		
Elbow		
Mitre		

Test No. 3: Volume Collected (liters):		Time (s):
Enlargement		
Contraction		
Long Bend		
Short Bend		
Elbow		
Mitre		
Test No. 4: Volume Collected (liters):		Time (s):
Enlargement		
Contraction		
Long Bend		
Short Bend		
Elbow		
Mitre		
Test No. 5: Volume Collected (liters):		Time (s):
Enlargement		
Contraction		
Long Bend		
Short Bend		
Elbow		
Mitre		

Part B – Head Loss Across Gate Valve

Head Loss (bar)	**Volume (liters)**	**Time (s)**
0.3		
0.6		
0.9		
Water Temperature:		

12.9 CALCULATIONS

Calculate the values of the discharge, flow velocity, velocity head, and Reynolds number for each experiment, as well as the K values for each fitting and the gate valve. Record your calculations in the following sample Result Tables.

Result Table

Part A – Head Loss Across Pipe Fittings

Test No:		Flow Rate Q (m^3/s):			Velocity v (m/s):		
Fitting	**h_1 (m)**	**h_2 (m)**	**$\Delta h = h_1 - h_2$ (m)**	**Corrected Δh (m)**	**$v^2/2g$ (m)**	**K**	**Reynolds Number**
Enlargement							
Contraction							
Long Bend							
Short Bend							
Elbow							
Mitre							

Part B – Head Loss Across Pipe Fittings

Head Loss Δh		Volume (m^3)	Time (s)	Flow Rate Q (m^3/s)	Velocity (m/s)	$v^2/2g$ (m)	K	Reynolds Number
(bar)	(m)							
0.3								
0.6								
0.9								

12.10 REPORT

Use the template provided to prepare your lab report for this experiment. Your report should include the following:

1. Table(s) of raw data
2. Table(s) of results
3. For Part A, on one graph, plot the head loss across the fittings {\Delta{h}} (y-axis) against the velocity head (x-axis). On the second graph, plot the K values for the fittings (y-axis)

against the flow rate Q (x-axis).

4. For Part B, on one graph, plot the valve head losses {\Delta{h}} (y-axis) against the velocity head (x-axis). On the second graph, plot the K values for the valve (y-axis) against the flow rate Q (x-axis).
5. Comment on any relationships noticed in the graphs for Parts A and B. What is the dependence of head losses across pipe fittings upon the velocity head?
6. Is it justifiable to treat the loss coefficient as constant for a given fitting?
7. In Part B, how does the loss coefficient for a gate valve vary with the extent of opening the valve?
8. Examine the Reynolds number obtained. Are the flows laminar or turbulent?

END