

# LABORATORY MANUAL



# DEPARTMENT OF MECHANICAL ENGINEERING

UNIVERSITY OF ENGINEERING & SCIENCE TECHNOLOGY

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### Preface

In most of the engineering institutions, the laboratory course forms an integral form of the basic course in Fluid Mechanics at undergraduate level. The experiments to be performed in a laboratory should ideally be designed in such a way as to reinforce the understanding of the basic principles as well as help the students to visualize the various phenomenon encountered in different applications.

The objective of this manual is to familiarize the students with practical skills, measurement techniques and interpretation of results. It is intended to make this manual self-contained in all respects, so that it can be used as a laboratory manual. In all the experiments, the relevant theory and general guidelines for the procedure to be followed have been given. Tabular sheets for entering the observations have also been provided in each experiment while graph sheets have been included wherever necessary.

It is suggested that the students should complete the computations, is the laboratory itself. However the students are advised to refer to the relevant text before interpreting the results and writing a permanent discussion. The questions provided at the end of each experiment will reinforce the students understanding of the subject and also help them to prepare for viva-voce exams.

### **General Instructions to Students**

- The purpose of this laboratory is to reinforce and enhance your understanding of the fundamentals of Fluid mechanics and Hydraulic machines. The experiments here are designed to demonstrate the applications of the basic fluid mechanics principles and to provide a more intuitive and physical understanding of the theory. The main objective is to introduce a variety of classical experimental and diagnostic techniques, and the principles behind these techniques. This laboratory exercise also provides practice in making engineering judgments, estimates and assessing the reliability of your measurements, skills which are very important in all engineering disciplines.
- Read the lab manual and any background material needed before you come to the lab. You must be prepared for your experiments before coming to the lab. In many cases you may have to go back to your fluid mechanics textbooks to review the principles dealt with in the experiment.
- Actively participate in class and don't hesitate to ask questions. Utilize the teaching assistants. You should be well prepared before coming to the laboratory, unannounced questions may be asked at any time during the lab.
- Carelessness in personal conduct or in handling equipment may result in serious injury to the individual or the equipment. Do not run near moving machinery. Always be on the alert for strange sounds. Guard against entangling clothes in moving parts of machinery.
- Students must follow the proper dress code inside the laboratory. To protect clothing from dirt, wear a lab apron. Long hair should be tied back.
- Calculator, graph sheets and drawing accessories are mandatory.
- In performing the experiments, proceed carefully to minimize any water spills, especially on the electric circuits and wire.
- Make your workplace clean before leaving the laboratory. Maintain silence, order and discipline inside the lab.
- Cell phones are not allowed inside the laboratory.
- Any injury no matter how small must be reported to the instructor immediately.
- Wish you a nice experience in this lab

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# List of Experiments

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Experiment No. 2	To investigate the factors affecting the stability of a floating body, and to determine the metacentric height and hence the position of the metacenter for the model barge
Experiment No. 3	To visualize the flow lines around wing profile submerged hydrodynamic model in a fluid current aerodynamic
Experiment No. 4	To observe the Laminar, Transitional and Turbulent flow and to determine the corresponding Reynolds number by using Osborne Reynolds Apparatus
Experiment No. 5	To determine the hydraulic coefficient ( $C_v$ , $C_d$ and $C_c$ ) by tracing the jet trajectory from a given orifice.
Experiment No. 6	To verify experimentally the validity of Bernoulli's equation for fluid flowing in a tapered duct by using Bernoulli Flow Apparatus.
Experiment No. 7	To determine the loss factors for flow through a range of pipe fittings including bends, a contraction, an enlargement and gate valve.
Experiment No. 8	To observe cavitation phenomena with forced conduction
Experiment No. 9	To study the characteristics of the surface profile and angular velocity, and determine a relation between surface profile and total head for the free and forced vortex.
Experiment No. 10	To investigate the characteristics of flow through an orifice and to calculate the coefficient of discharge $C_d$ , coefficient of velocity $C_v$ , and coefficient of contraction $C_c$ at a number of pressure heads for different orifices.
Experiment No. 11	To determine experimentally the volume flow rate by utilizing three basic types of flow meters including flow meter, Venturi meter and Orifice meter and comparing the results against the flow measurement by Volumetric Method through the hydraulics bench.
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# 1 LAB SESSION 1

To study the characteristics of Hydraulic Bench and determine the volume and the mass flow rates of fluid flowing through this unit.

### **1.1 Learning Objective:**

At the end of this study, the student will be able to:

• To study the different parts of Hydraulic Bench.

#### 1.2 Apparatus

In order to complete the demonstration we need a number of pieces of equipment.

- 1. The FME-00 Hydraulic Bench which allows us to measure flow by timed volume collection.
- 2. Stop watch.

### 1.3 Main Parts of Hydraulic Bench

- 1. Pump/motor drive (centrifugal discharge)
- 2. Sump Tank
- 3. Transparent pipe
- 4. Flow control valve
- 5. Drain valve
- 6. Side channel
- 7. Open channel
- 8. Volumetric measuring tank
- 9. Stilling baffle
- 10. Sight tube (Manometer)
- 11. Measuring cylinder
- 12. Dump valve

### **1.4 Related theory**

The bench is constructed from lightweight corrosion resistant plastic and is mounted on wheels for mobility. The bench top incorporates an open channel with side channels to support the accessory on test.

Volumetric measurement is integral and has been chosen in preference to other methods of flow measurement for its ease of use, accuracy and safety in use (no heavy weights for students to handle).

The volumetric measuring tank is stepped to accommodate low or high flow rates. A stilling baffle reduces turbulence and a remote sight tube with scale gives an instantaneous indication of water level. A measuring cylinder is included in the supply for measurement of very small flow rates.

A dump valve in the base of the volumetric tank is operated by a remote actuator. Opening the dump valve returns the measured volume of water to the sump in the base of the bench for recycling. An overflow in the volumetric tank avoids flooding.



Figure 1.1: Hydraulic Bench Unit

Water is drawn from the sump tank by a centrifugal pump and a panel mounted control valve regulates the flow. An easy-to-use quick release pipe connector situated in the bench top allows for the rapid exchange of accessories without the need for hand tools.

Each accessory is supplied as a complete piece of equipment needing no additional service items other than the Hydraulics Bench. When coupled to the bench they are immediately ready for use.

#### **1.5 Experimental procedure:**

- 1) Set up the equipment and identify its components.
- 2) Connect one end of the hose to the hydraulic bench supply and place the other end in the volumetric tank; in order to facilitate the timed volume collections.
- Start the pump of the hydraulic bench and initiate the flow by gradually opening the flow control valve.
- 4) After the steady state is achieved, direct the water outlet hose into the bench volumetric tank. Collect water with a particular capacity (3 *l*,5 *l*, or 10 *l* for example) and record the time taken for the water to fill it up. Take at least 3 measurements and record the timings in order to calculate (average) volume flow rate.
- 5) Divide the volume collected in the volumetric tank by the time taken to collect that capacity in order to calculate average volume flow rate.
- 6) Compute the average mass flow rate.
- 7) Repeat the experiment by varying the flow of water through the hydraulic bench by adjusting the flow control valve.
- 8) Compute the average values of volume and mass flow rates.

#### 1.6 Observations & Calculations

$$Q_i = \frac{V_{ol}}{t}$$
$$\dot{m} = \rho Q$$

$$X_{av} = \frac{1}{n} (x_1 + x_2 + x_3)$$
  
$$S_x = \sqrt{\frac{1}{n-1} ((x_1 - x_{av})^2 + (x_2 - x_{av})^2 + (x_3 - x_{av})^2)}$$

Obs. n	Volume $V_{ol}(l)$	Time $t(s)$	Volume Flow rate $Q_i(m^3/s)$	Mass Flow rate $\dot{m}_i(kg/s)$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
		$Q_{av}$	$_g = \frac{\sum Q_i}{n} = m^3/s$	
		$\dot{m}_{av}$	$_g = \frac{\sum \dot{m}_i}{n} = kg/s$	

 Table 1.1: Calculation of volume flowrate and mass flowrate

# 1.7 Specimen Calculation

# 1.8 Statistical Analysis

**1.9 Conclusion:** 

# 2 LAB SESSION 2

To investigate the factors affecting the stability of a floating body, and to determine the metacentric height and hence the position of the metacentre for the model barge.

### 2.1 Learning Objective:

At the end of this study, the student will be able to:

• To study the stability of a floating body

#### 2.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Hydraulic bench
- 2. Metacentric height apparatus

### 2.3 Main Parts of Metacentric height apparatus

- 1. Prismatic base of methacrylate
- 2. Vertical mast
- 3. Mobile mass
- 4. Scale

### 2.4 Related theory

#### Metacentre:

"Whenever a body, floating in a liquid, is given a small angular displacement, it starts oscillating about some point. This point, about which the body starts oscillating, is called metacentre."

#### **Metacentric Height:**

"The distance between centre of gravity of a floating body and the metacentre (i.e. distance between cg and m as shown in) is called metacentric height."



Metacentric height of a floating body is a direct measure of its stability.

More the metacentric height of a floating body, more it will stable and vice versa.

Some values of metacentric height:

- Merchant Ships = up to 1.0 m
- Sailing Ships = up to 1.5 m
- Battle Ships = up to 2.0 m
- River Craft = up to 3.5 m

#### **Conditions of Equilibrium of a Floating Body:**

A body is said to be in equilibrium, when it remains in steady state. While floating in a liquid following are the three conditions of equilibrium of a floating body:

- 1. Stable Equilibrium
- 2. Unstable Equilibrium
- 3. Neutral Equilibrium

#### Stable Equilibrium:

A body is said to be in a stable equilibrium, if it returns back to its original position, when given a small angular displacement. This happens when metacentre (M) is higher than centre of gravity (G) of the floating body.

#### **Unstable Equilibrium:**

A body is said to be in an unstable equilibrium, if it does not return back to its original position, when given a small angular displacement. This happens when metacentre (M) is lower than centre of gravity (G) of the floating body.

#### Neutral Equilibrium:

A body is said to be in a neutral equilibrium, if it occupies a new position and remains at rest in this new position, when given a small angular displacement. This happens when metacentre (M) coincides with centre of gravity (G) of the floating body.

Determination and analysis of the stability of floating bodies, such as ships, rafts, barges and pontoons, is important throughout many branches of engineering. This experiment allows

students to determine the stability of a barge with its centre of gravity at various heights. They can then compare this to predictions calculated from theory.

On this item the position of the metacentre can be varied to produce stable and unstable equilibrium. The equipment consists of a plastic rectangular floating pontoon, the centre of gravity of which can be varied by an adjustable weight which slides and can be clamped in any position on a vertical mast.

A single plumb-bob is suspended from the mast which indicates the angle of heel on a calibrated scale. A weight with lateral adjustment allows the degree of heel to be varied and hence the stability of the pontoon determined.



Figure 2.1: Metacentric height apparatus

#### 2.5 Experimental procedure:

- 1) Set up the equipment on the volumetric tank of the hydraulic bench (some quantity of water should be present in the volumetric tank of the hydraulic bench).
- 2) Adjust the position of the horizontally movable mass to the right and record its distance from the vertical rod.
- 3) Adjust the position of the vertically movable mass and record its distance from the horizontal rod.
- 4) For the current position of the horizontally and vertically movable masses, measure the angle of tilt.

- 5) Compute the metacentric height for this position of the movable masses.
- 6) Repeat steps 2-5 for various positions of the movable masses and the water level in the volumetric tank.
- 7) Adjust the position of the horizontally movable mass to the left and record its distance from the vertical rod.
- 8) Adjust the position of the vertically movable mass and record its distance from the horizontal rod.
- 9) For the current position of the horizontally and vertically movable masses, measure the angle of tilt.
- 10) Compute the metacentric height for this position of the movable masses.
- 11) Repeat steps 7 11 for various positions of the movable masses and the water level in the volumetric tank.

12) Compare the results.

#### 2.6 Observations & Calculations

#### **Theoretical:**

GM = BM + OB - OG

$$BM = \frac{I}{V}$$

V = submerged volume

$$I = \frac{bd^3}{12}$$

$$V = b \times hd$$

b = Longitude = 353 mm

d = Width = 204 mm

h = height of pontoon submerged in water

$$V = \frac{m}{\rho}$$

m = Total mass of pontoon

$$\rho$$
 = Density of Water

$$OB = \frac{1}{2} \times depth \ of \ immersion$$

$$OB = 0.2 \times \frac{V}{bd}$$

OG = Centre of gravity from the bottom surface of the body



#### **Practically:**

l = distance of movable mass from vertical axis of barge

 $m_H$  = moveable mass in horizontal direction =

M = mass of the barge =

GM = metacentric height

 $\theta =$ angle of tilt

$$\mathrm{GM} = \frac{m_H l}{M \, \tan \theta}$$

$$X_{av} = \frac{1}{n} (x_1 + x_2 + x_3)$$
  
$$S_x = \sqrt{\frac{1}{n-1} ((x_1 - x_{av})^2 + (x_2 - x_{av})^2 + (x_3 - x_{av})^2)}$$

Obs.	$l_{right}(cm)$	θ (°)	GM ( <i>cm</i> )	$l_{left}(cm)$	θ (°)	GM ( <i>cm</i> )
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

# 2.7 Specimen Calculation

# 2.8 Statistical analysis

2.9 Conclusion:

# 3 LAB SESSION 3

To visualize the flow lines around wing profile submerged hydrodynamic model in a fluid current aerodynamic.

### 3.1 Learning Objectives:

At the end of this study, the student will be able to:

- To study the movement in a fluid, when it takes place around a fixed body.
- To study the streak lines and streamlines in a fluid flow.

#### 3.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Hydraulic bench
- 2. Flow Visualization apparatus

### 3.3 Main Parts of Flow Visualization Channel Unit

- 1. Ink tank
- 2. Needles for the injection of the ink
- 3. Channel for the flow study
- 4. Damping tank

#### 3.4 Related theory

For the study of the current lines, they will be different depending on the Reynold's number they have. If the Reynold's number is too big, turbulence will appear at the back of the models. The study of aerodynamic eliminates those turbulences.

Flow visualization is the art of making flow patterns visible. Most fluids (air, water, etc.) are transparent, thus their flow patterns are invisible to the naked eye without methods to make them visible.

Historically, such methods included experimental methods. With the development of computer models and CFD simulating flow processes (e.g. the distribution of air-conditioned air in a new car), purely computational methods have been developed.

#### Methods of Visualization:

- Surface flow visualization: This reveals the flow streamlines in the limit as a solid surface is approached. Coloured oil applied to the surface of a wind tunnel model provides one example (the oil responds to the surface shear stress and forms a pattern).
- Particle tracer methods: Particles, such as smoke or microspheres, can be added to a flow to trace the fluid motion. We can illuminate the particles with a sheet of laser light in order to visualize a slice of a complicated fluid flow pattern. Assuming that the particles faithfully follow the streamlines of the flow, we can not only visualize the flow but also measure its velocity using the particle image velocimetry or particle tracking velocimetry methods. Particles with densities that match that of the fluid flow will exhibit the most accurate visualization.
- Optical methods: Some flows reveal their patterns by way of changes in their optical refractive index. More directly, dyes can be added to (usually liquid) flows to measure concentrations; typically employing the light attenuation or laser-induced fluorescence techniques.

In scientific visualization flows are visualized with two main methods:

- Analytical methods that analyse a given flow and show properties like streamlines, streak lines, and path lines. The flow can either be given in a finite representation or as a smooth function.
- Texture advection methods that "bend" textures (or images) according to the flow. As the image is always finite (the flow though could be given as a smooth function), these methods will visualize approximations of the real flow.
- **Streamlines** are a family of curves that are instantaneously tangent to the velocity vector of the flow. These show the direction a massless fluid element will travel in at any point in time.
- **Streak lines** are the loci of points of all the fluid particles that have passed continuously through a particular spatial point in the past. Dye steadily injected into the fluid at a fixed point extends along a streak line.
- **Path lines** are the trajectories that individual fluid particles follow. These can be thought of as "recording" the path of a fluid element in the flow over a certain period. The direction the path takes will be determined by the streamlines of the fluid at each moment in time.



**Figure 3.1: Flow visualization apparatus** 

A **Streamline** is one that drawn is tangential to the velocity vector at every point in the flow at a given instant and forms a powerful tool in understanding flows. **Path line** is the line traced by a given particle. This is generated by injecting a dye into the fluid and following its path by photography or other means. **Streak line** concentrates on fluid particles that have gone through a fixed station or point. At some instant of time the position of all these particles are marked and a line is drawn through them. Such a line is called a streak line.

In a steady flow the streamline, path line and streak line all coincide. In an unsteady flow they can be different. Streamlines are easily generated mathematically while path line and streak lines are obtained through experiments.

#### 3.5 Experimental procedure:

- 1 Place the model to be used in the channel with the screws supplied. Wedge models (as well as circular ones) will be placed in the central hole.
- 2 For a better visualization of the flow, we must use an ink, injected through the hypodermic needles.
- 3 It is recommended to use a vegetable ink with density similar to that of the water, so the flow lines are clear.

- 4 Start the pump in order that the water begins to circulate through channel, being the ink valve closed. Adjust the flow through the channel with the control valve of the hydraulic bench.
- 5 To study the submerged bodies in a fluid current, we will slide the trap from top to bottom, in order that the water covers the models completely.
- 6 Open the ink control valve located in the base of the tank and adjust the current density.
- 7 Repeat this procedure with all models supplied. With the discharge adjustable plate at the highest position, the channel will operate full of water, allowing the visualization of the flow with flow models around and over submerged objects.
- 8 To see the visualization of the flow lines clearly, we can place a blank sheet at the back of the channel.
- 9 See how lines vary depending on the flow, when we increase this flow progressively.

#### **3.6 Conclusion:**

## 4 LAB SESSION 4

To observe the Laminar, Transitional and Turbulent flow and to determine the corresponding Reynolds number by using Osborne Reynolds Apparatus

### 4.1 Learning Objectives:

At the end of this study, the student will be able to:

- Know the importance of Reynold's number.
- Know the difference among laminar, transition and turbulent flows.

#### 4.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Osborne Reynolds Apparatus
- 2. Hydraulic bench
- 3. Stop watch

#### 4.3 Main Parts of Osborne Reynolds apparatus

- 1. Ink tank
- 2. Colouring liquid injection valve
- 3. Screw
- 4. Injector
- 5. Nozzle
- 6. Visualization flow tube
- 7. Flow control valve
- 8. Inlet pipe
- 9. Overflow outlet pipe
- 10. Overflow

#### 4.4 Related theory

The unit has been designed for students experiment on the laminar, transition and turbulent flow. It consists of a transparent header tank and a flow visualization pipe. Flow through this pipe is regulated using a control valve at the discharge end. The water flow rate through the pipe can be measured using the volumetric tank (or measuring cylinder) of a Hydraulics Bench. Velocity of the water can therefore be determined to allow for the calculation of Reynolds' number. A dye injection system is installed on top of the header tank so that flow pattern in the pipe can be visualized.

The Reynolds number, R, is used as useful parameter to classify the regime type in a flow. The determination of the Reynolds number is a function of the critical velocity of the fluid. The critical is defined as the fluid velocity in which flow regime is changed; laminar to turbulence. The object of this experiment is to verify that the Reynolds number fluctuates between 2000 and 2100.

 $\begin{array}{l} \mbox{Where V = Velocity in m/s} & R_e = VD/\upsilon \\ \mbox{D = Diameter of the tube in meters} \\ \mbox{$\upsilon = Kinematic viscosity of water = 1 x 10^{-6} m^2/s at 20^{\circ}C temp.} \\ \mbox{For } R_e > 4000 \mbox{ flow is turbulent} \\ \mbox{2000 < } R_e < 4000 \mbox{ flow is transition} \\ \mbox{$R_e < 2000 \mbox{ flow is laminar}} \end{array}$ 



Figure 4.1: Osborne Reynolds Demonstration apparatus

#### 4.5 Experimental procedure:

- 1. Set up the equipment on the hydraulic bench so that its base is horizontal.
- 2. Check if the drain valve is open and keep it wide open and check whether the outlet pipe goes to the drain. Ensure that the rig outflow valve is positioned above the volumetric tank; in order to facilitate the timed volume collections.
- 3. Connect the inlet pipe to the bench flow supply. Make sure that the exit hose is positioned so that it will drain into the sink tank of the bench.
- 4. Fill up the dye reservoir with ink.
- 5. Start the pump of the Hydraulic Bench and establish the water supply.
- 6. Open the outflow valve to test the unit. Check for any leaking of water and proceed to inject the ink.
- 7. Lower the dye injector until it is seen in the glass tube.
- 8. Open the inlet valve and allow water to enter tank.
- 9. Ensure a small overflow spillage through the over flow tube to maintain a constant level.
- 10. Allow water to settle for a few minutes.
- 11. Open the flow control valve fractionally to let water flow through the visualizing tube.
- 12. Slowly adjust the dye control needle valve until a slow flow with dye injection is achieved.
- 13. Regulate the water inlet and outlet valve until an identifiable dye line is achieved.
- 14. After the steady state is achieved, direct the water outlet hose into the bench volumetric tank. Collect water with a particular capacity (3 *l*,5 *l*, or 10 *l* for example) and record the time taken for the water to fill it up. Take at least 3 measurements and record the timings in order to calculate (average) volume flow rate.
- 15. Compute Reynolds number and observe the flow.
- 16. Repeat the experiment by regulating water inlet and outlet valve to produce different flows.

#### 4.6 Observations & Calculations

cross sectional Area of tube  $= A = \frac{\pi}{4}D^2$ diameter of tube  $= D = 10 \ mm = 0.01m$ Reynolds number  $= Re = \frac{\rho VD}{P} = \frac{VD}{P}$ 

eynolds number = 
$$Re = \frac{\mu v D}{\mu} = \frac{v D}{v}$$

$$\begin{aligned} X_{av} &= \frac{1}{n} \left( x_1 + x_2 + x_3 \right) \\ S_x &= \sqrt{\frac{1}{n-1} \left( (x_1 - x_{av})^2 + (x_2 - x_{av})^2 + (x_3 - x_{av})^2 \right)} \end{aligned}$$

 Table 4.1: Calculation of Reynold's number

Obs.	∀ ( <i>l</i> )	<i>t</i> ( <i>s</i> )	$Q(m^3/s)$	T (°C)	$\nu (m^2/s)$	V(m/s)	Re	Type of Flow
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

# 4.7 Specimen calculation

# 4.8 Statistical Analysis

R<sub>e</sub> Number in Laminar =

Re Number in Transient =

Re Number in Turbulent =

# 4.9 Conclusion:

# 5 LAB SESSION 5

To determine the hydraulic coefficient ( $C_v$ ,  $C_d$  and  $C_c$ ) by tracing the jet trajectory from a given orifice.

### 5.1 Learning Objectives:

At the end of this study, the student will be able to:

- Determine the drain coefficient for an orifice of small sized under constant height of flow
- Determine the drain coefficient for an orifice of small sized under variable height of flow

### 5.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Orifice and free jet flow apparatus
- 2. Hydraulic bench
- 3. Stop watch
- 4. Meter rod
- 5. Paper and marker
- 6. Orifices of various diameters

#### 5.3 Main Parts of orifice and free jet flow apparatus

- 1. Methacrylate tank
- 2. Vertical needles
- 3. Silk screen scale
- 4. Orifice
- 5. Inlet pipe
- 6. Overflow tube

### 5.4 Related theory

This apparatus consist mainly of a clear acrylic tank with a small orifice near the bottom of the tank. There is an inlet hose through which the tank is filled and supplied with water and there is an adjustable overflow pipe near the top of the tank through which the level of water in the tank can be perfectly maintained. The tank is mounted on a frame along with a recording system that is used to measure the jet of water produced from the orifice when in use. The recording system consists of a clipboard and adjustable needles. The needles can be adjusted in height to

correspond with the arc of the water jet. Paper can be mounted against the clipboard and the position of the tops of the needles can be recorded on the paper.



Figure 5.1: Orifice and free jet flow apparatus

### 5.5 Experimental procedure:

- 1) Set up the equipment on the hydraulic bench so that its base is horizontal.
- Check if the drain valve is open and keep it wide open and check whether the outlet pipe goes to the drain. Ensure that the rig outflow valve is positioned above the volumetric tank; in order to facilitate the timed volume collections.
- 3) Connect the inlet pipe to the bench flow supply. Make sure that the exit hose from the adjustable overflow pipe is positioned so that it will drain into the sink tank of the bench. Close the bench valve and the apparatus flow control valve and start the pump.
- 4) Through visual inspection, level the apparatus using the adjustable feet. Measure the diameter of the orifice in all orifice plates. Finally place paper in the clamp against the clip board (It may be needed to tape two pieces of paper together to stretch across the whole of the clipboard).

- 5) Raise all of the needles to their highest position where they are "out of the way". We will call this starting position. Make sure that one of the orifice plates is in position on the tank. Place the adjustable overflow pipe such that it is relatively low. Turn on the water supply. Once the water has reached the level where it is spilling into the overflow pipe, adjust the flow so that it just barely trickles into the pipe. Record the water level or head (*h*). At this time the water jet should be formed and protruding forcefully from the tank.
- 6) After the steady state is achieved, direct the water outlet hose into the bench volumetric tank. Collect water with a particular capacity (3 *l*,5 *l*, or 10 *l* for example) and record the time taken for the water to fill it up. Take at least 3 measurements and record the timings in order to calculate (average) volume flow rate.
- 7) Adjust the height of each needle such that the tip of the needle is just above the water jet as it passes underneath.



8) Once all of the needles are set, mark the position of the top of each needle on the paper against the clipboard. The vena contracta of the water jet should serve as the datum, the first mark, the furthermost mark to the left, i.e. the first mark will be a bit to the left of the clip board (the x component will be the x location of the vena contracta and the y component will be the same as the y component of the first needle. (The vena contracta is the place where the water jet narrows from the diameter of the orifice to the diameter of the rest of the jet. The position of the vena contracta is usually very close to the orifice. Some system of notation should devised such that each set of marks can be distinguished (from each trial) from all other sets of marks. Once the marks are made, return the needles to starting position.



- 9) Repeat steps 2 to 4 for more conditions of head. It is recommended that simply increase the water level each time until the top of tank is reached. To increase the water, simply raise the position of the over flow pipe. It may also be needed to increase the rate of the input water flow rate.
- 10) Change the orifice plate and repeat the experiment again. It may be needed to use another sheet of paper on the clipboard or to turn over the one that is being currently used.



- 11) Calculate the xdistance and y distance from each trial of all the orifices.
- 12) Calculate  $C_v, C_d$  and  $C_c$ .
- 13) Plot a graph comparing the cross sectional area of the orifices to the  $C_d$ .
- 14) Plot a graph comparing the cross sectional area of the orifices to the C<sub>v</sub>.
- 15) Plot a graph comparing the cross sectional area of the orifices to the  $C_c$ .
- 16) Plot a graph comparing the cross sectional area of the orifices to the  $C_d$ ,  $C_v$  and  $C_c$  on the same graph paper.
- 17) Plot graphs of  $V_i$  against  $V_o$  and  $V_a$  and show the results on the same graph.

#### 5.6 Observations & Calculations

Diameter of the orifice = d

Cross sectional area of the orifice 
$$= A = \frac{\pi}{4}d^2$$

Actual discharge = 
$$Q_a = \frac{volume}{time} = \frac{\forall}{t}$$

Ideal velocity =  $V_i = \sqrt{2gh}$  h = water head in the tank = vertical distance of water surface in the tank from orifice Ideal discharge =  $Q_i = AV_i = A\sqrt{2gh}$  x = horizontal distance of the furthermost needle from the vena contracta y = vertical distance over the span of x

$$C_{v} = \frac{x}{2\sqrt{yh}}, \qquad C_{v} = \frac{V_{a}}{V_{i}}$$

$$C_{d} = \frac{Q_{a}}{Q_{i}} = \frac{Q_{a}}{A\sqrt{2gh}}$$

$$C_{c} = \frac{C_{d}}{C_{v}}$$

$$X_{av} = \frac{1}{n} (x_{1} + x_{2} + x_{3})$$

$$S_{x} = \sqrt{\frac{1}{n-1} ((x_{1} - x_{av})^{2} + (x_{2} - x_{av})^{2} + (x_{3} - x_{av})^{2})}$$



Orifice 1 ( $d = 3.5 mm$ , $A = mm^2$ )											
Obs.	h (mm)	$Q_i(l/s)$	∀ (l)	<i>t</i> ( <i>s</i> )	$Q_a(l/s)$	<i>x</i> ( <i>mm</i> )	<i>y</i> ( <i>mm</i> )	$C_{v}$	$C_d$	$C_c$	V <sub>a</sub> (mm/s)
1											
2											
3											
4											
5											
6											
7											
8											
9											
	-		Orific	ce 2 (d	= 6 mm,	A =	$mm^2$ )	-			
Obs.	h (mm)	$Q_i(l/s)$	∀ (l)	<i>t</i> ( <i>s</i> )	$Q_a(l/s)$	<i>x</i> ( <i>mm</i> )	y (mm)	$C_{v}$	$C_d$	$C_{c}$	$V_a$ (mm/s)
1									u u	- 6	<b>u</b> ( <b>b u</b> )
1										- L	
2										- L	
2 3											
2 3 4											
2 3 4 5											
$ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} $											
2 3 4 5 6 7											
2 3 4 5 6 7 8											
## 5.7 Specimen Calculation

- 5.8 Statistical Analysis
- $C_d =$
- $C_v =$
- $C_c =$
- 5.9 Conclusion:

## 6 LAB SESSION 6

To verify experimentally the validity of Bernoulli's equation for fluid flowing in a tapered duct by using Bernoulli Flow Apparatus.

### 6.1 Learning Objectives:

At the end of this study, the student will be able to:

- To demonstrate the variation of the pressure along a converging-diverging pipe section.
- To verify the Bernoulli's Theorem..

#### 6.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Hydraulic bench
- 2. Venturi type Bernoulli Flow Apparatus with Column Manometers P
- 3. Pitot Static Tube
- 4. Stop watch

### 6.3 Main Parts of Bernoulli's Theorem Demonstration Unit

- Manometeric tubes panel
- Purge valve
- Regulating Flow control Valve
- Convergent- Divergent Tube
- Pitot Tube

#### 6.4 Related theory

The Bernoulli's Theorem states that the sum of pressure head, velocity head and the potential head is constant along a stream line for a steady, in viscid and incompressible flow of fluid. Bernoulli's Theorem Demonstration Apparatus is a bench top unit and it illustrates the circumstances to which Bernoulli's theorem can be applied. The apparatus consists of a transparent venturi tube. Wall pressure tapings are provided along the converging and diverging portions of the venturi to measure the static pressure distribution. Pitot tubes are provided to along the centre line of the venturi. Static pressures are measured using multi-tube manometer having a manifold with an air bleed valve. The characteristics of the flow in both convergent and divergent portions.

Considering the flow in two different sections of a pipe, and applying the law of conservation of the energy, Bernoulli's equation may be written as:

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2$$
(1)

Where, in this equipment,  $Z_1{=}\,Z_2$  ; and  $P{=}\,\gamma$  . h

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

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

$$\frac{p}{p'g} + \frac{v^4}{2 \cdot g} = h^* = const.$$
 (This is the total head at a cross section).

P = fluid static pressure at the cross section in  $N/m^2$ .

- $\rho$  = density of the flowing fluid in  $kg/m^3$
- g = acceleration due to gravity in  $m/s^2$  (its value is 9.81  $m/s^2 = 9810 mm/s^2$ )
- v = mean velocity of fluid flow at the cross section in *m/s*
- z = elevation head of the centre of the cross section with respect to a datum z=0
- $h^* = \text{total (stagnation) head in } m$

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

The sum of the three previous terms is constant and so, Bernoulli's theorem can be shown as:

$$H = \frac{P}{\gamma} + \frac{V^2}{2g}$$

Where:

 $\frac{V^2}{2g}$  = Kinetic height

 $H = \frac{P}{\gamma}$  = Piezo-metric height: it is the height of one water column associated with the pressure of the gravitation field.



Let Point 1 be the stagnation point in above figure and Point 2 be the static point. In a Pitot tube, the air velocity at the stagnation point is zero while the air velocity at the static point is constant. The elevation of the two points is the same. If the pressure at the stagnation and static points is measured, the velocity at the static point can be determined from Equation (1).

Bernoulli's law indicates that, if an inviscid fluid is flowing along a pipe of varying cross section, then the pressure is lower at constrictions where the velocity is higher, and higher where the pipe opens out and the fluid stagnates. Many people find this situation paradoxical when they first encounter it (higher velocity, lower pressure). The well-known Bernoulli equation is derived under the following assumptions:

- 1. fluid is incompressible (density  $\rho$  is constant);
- 2. flow is steady:  $\partial_{\partial t} = 0$
- 3. flow is frictionless  $(\tau = 0)$ ;
- 4. along a streamline;



Figure 6.1: Bernoulli's Theorem Demonstration Unit

#### 6.5 Experimental procedure:

- 1) Set up the equipment on the hydraulic bench so that its base is horizontal. This is necessary for accurate height measurement from the manometer.
- 2) Check if the drain valve is open and keep it wide open and check whether the outlet pipe goes to the drain. Ensure that the rig outflow valve is positioned above the volumetric tank; in order to facilitate the timed volume collections.
- 3) Connect the rig inlet to the bench flow supply, close the bench valve and the apparatus flow control valve and start the pump. Initiate flow through the Venturi test section by gradually opening the inlet valve.
- 4) Check that all manometer tubes are properly connected to the corresponding pressure taps and are air-bubble free. If needed flush the air-bubbles by slowly closing the exit valve and draining the water (and the air-bubbles) through the manometer tubing.
- 5) Adjust both (inlet and outlet) valves so that the maximum difference in water levels between tapping point 1 and 3 is achieved.
- 6) Wait for some time for the level in manometer tubes to stabilize (it takes some time for it to reach steady state).
- 7) After the steady state is achieved, direct the water outlet hose into the bench volumetric tank. Collect water with a particular capacity (3 l, 5 l, or 10 l for example) and record the

time taken for the water to fill it up. Take at least 3 measurements and record the timings in order to calculate (average) volume flow rate.

- 8) Gently push (slide) the Pitot (total head measuring) tube, connected to manometer 7, so that its end reaches the cross section of the Venturi tube at 1, for example. Wait for some time and note down the readings from manometers 7 and 1. The reading shown by manometer 7 is the sum of the pressure and velocity heads, i.e. the total (or stagnation) head, because the Pitot tube is held against the flow of fluid forcing it to a stop (zero velocity). The reading in manometer 1 measures just the pressure head (h) because it is connected to the Venturi tube pressure tap, which does not obstruct the flow, thus measuring the flow static pressure at that point.
- 9) Repeat step 6 for other cross sections (2, 3,4, 5 and 6).
- 10) Plot the pressure distributions (pressure heads) against the distance from inlet to exit along the length of the venturi.

₩.

#### 6.6 Observations and Calculations:

$$Q_{i} = \frac{v_{i}}{t}$$

$$A_{i} = \frac{\pi}{4}D_{i}^{2}$$

$$V_{iB} = \sqrt{2g(h_{t} - h_{i})}$$

$$V_{iC} = \frac{Q_{avg}}{A_{i}}$$

% Error in experimental and theoratical velocities =  $e_v = \frac{V_{iB} - V_{iC}}{V_{iC}}$ 

$$h_{t,th} = h_i + \frac{V_i^2}{2g}$$

% Error in experimental and theoratical total heads  $= e_h = \frac{h_{t,th} - h_{t,exp}}{h_{t,th}}$ 

$$X_{av} = \frac{1}{n} (x_1 + x_2 + x_3)$$
  
$$S_x = \sqrt{\frac{1}{n-1} ((x_1 - x_{av})^2 + (x_2 - x_{av})^2 + (x_3 - x_{av})^2)}$$

Observation	Volume $\forall_i (l)$	Time t (sec)	Volume Flow rate $Q_i(l/s)$
1			
2			
3			
	$Q_{avg} = \frac{\sum Q_i}{3} =$	= <i>l/s</i> =	mm <sup>3</sup> /s

#### Table 6.1: Volume flowrate measurement

#### Table 6.2: Velocity measurement by using two different equations

Cross Section	Usin	g Bernoulli	Equation	Using	Equation	%Error	
i	He	ead	Velocity	Diameter	Area	Velocity	$e_v$
	$h_i(mm)$	$h_t(mm)$	$V_{iB}(mm/s)$	$D_i(mm)$	$A_i(mm^2)$	$V_{iC}(mm/s)$	
1							
2							
3							
4							
5							
6							

#### Table 6.3: Head measurement at different diameters

Cross Sectioni	Diameter	Area	Velocity		Head h (n	ım)	%Error
	$D_i(mm)$	$A_i(mm^2)$	$V_i(mm/s)$	h <sub>i</sub>	$h_{t,exp}$	h <sub>t,th</sub>	$e_h$
1							
2							
3							
4							
5							
6							

## 6.7 Specimen Calculation:

## 6.8 Statistical analysis:

6.9 Conclusion:

### 7 LAB SESSION 7

To determine the loss factors for flow through a range of pipe fittings including bends, a contraction, an enlargement and gate valve.

#### 7.1 Learning Objectives:

At the end of this study, the student will be able to:

- Know the causes of minor losses in a pipe flow
- Calculate the minor loses

#### 7.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Energy Losses in Bends Apparatus
- 2. Hydraulic bench
- 3. Stop watch

#### 7.3 Main Parts of Energy Losses in Bends Apparatus

- 1. Purge valve
- 2. Manometers
- 3. Water inlet and outlet pipes
- 4. Membrane Valve
- 5. Flow control valve
- 6. Short Elbow 90°
- 7. Middle elbow
- 8. Hand pump
- 9. Miter

#### 7.4 Related theory

The energy loss which occurs in a pipe fitting (so-called secondary loss) is commonly expressed in terms of a head loss (h, metres) in the form:

$$\Delta h = \frac{Kv^2}{2g}$$

Where K = the loss coefficient and v = mean velocity of flow into the fitting.

Because of the complexity of flow in many fittings, K is usually determined by experiment. For the pipe fitting experiment, the head loss is calculated from two manometer readings, taken before and after each fitting, and K is then determined as

$$K = \frac{\Delta h}{v^2 / 2g}$$

Due to the change in pipe cross-sectional area through the enlargement and contraction, the system experiences an additional change in static pressure. This change can be calculated as

$$\frac{{v_1}^2}{2g} - \frac{{v_2}^2}{2g}$$

To eliminate the effects of this area change on the measured head losses, this value should be added to the head loss readings for the enlargement and the contraction.

Note that (h1 – h2) will be negative for the enlargement and  $\frac{v_1^2}{2g} - \frac{v_2^2}{2g}$  will be negative for the contraction.

For the gate valve experiment, pressure difference before and after the gate is measured directly using a pressure gauge. This can then be converted to an equivalent head loss using the equation

1 bar = 10.2 m water

The loss coefficient may then be calculated as above for the gate valve.

The losses of kinetic energy of a fluid that circulates through a pipe. These are caused by mainly by abrupt variations of velocity due to:

- Abrupt changes of pipe section: widenings or narrowing's
- Perturbation of the normal current flow, due to changes of the direction caused by the existence of an elbow
- Friction



**Figure 7.1: Energy Losses in Bends Apparatus** 

### 7.5 Experimental procedure:

- 1. Assemble the equipment on hydraulic bench.
- 2. To connect the input tube from the equipment to the pulse mouth of the bench with the quick switch and connect a flexible conduct to its outlet, so that it can drain in the volumetric tank.
- 3. Fill the manometeric pipes following the procedure indicated in practice.
- 4. Once the system is pressurized, turn on the pump and open gradually and slightly the valve of the bench or group VC, while you open gradually the control valve of the equipment, VCC.
- 5. Once the valve of bench is completely open, regulate the flow with the control valve of the equipment, VCC.
- 6. Write down the readings indicated in the manometeric pipes which are associated with the short elbow of 90° etc. respectively.
- 7. Repeat the previous steps varying the flow by opening the control valve of the equipment.

### 7.6 Observations & Calculations

$$K = \frac{\Delta h}{v^2 / 2g}$$

Diameter of the pipe = 0.0196 m

$$X_{av} = \frac{1}{n} (x_1 + x_2 + x_3)$$
  
$$S_x = \sqrt{\frac{1}{n-1} ((x_1 - x_{av})^2 + (x_2 - x_{av})^2 + (x_3 - x_{av})^2)}$$

Table 7.1: Calculation of Loss coefficient K in bends or fittings

Obs.	Fitting	Manometer h <sub>n</sub>	Manometer h <sub>n+1</sub>	$\begin{array}{l} \text{Head loss} = \\ h_{n+1} - h_n \end{array}$	Volume (m <sup>3</sup> )	Flow rate (m <sup>3</sup> /s)	Velocity (m/s)	$K = \frac{\Delta h}{v^2 / 2g}$
1	Long bend							
2	Enlargement							
3	Contraction							
4	Short Elbow							
5	Elbow							
6	Miter							

## 7.7 Specimen calculation

7.8 Statistical Analysis

7.9 Conclusion:

## 8 LAB SESSION 8

To observe cavitation phenomena with forced conduction

#### 8.1 Learning Objectives:

At the end of this study, the student will be able to:

- To demonstrate the appearance and sound of cavitation in a hydraulic system.
- To demonstrate the conditions for cavitation to occur (liquid at its vapour pressure).
- To show how cavitation can be prevented by raising the static pressure of a liquid above its vapour pressure

#### 8.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Cavitation Demonstration Apparatus
- 2. Hydraulic bench
- 3. Stop watch

#### 8.3 Main Parts of Cavitation Demonstration Unit

- 1. Manometers
- 2. Throat section
- 3. Inlet and outlet pipe
- 4. Hydraulic Bench

#### 8.4 Related theory

In accordance with Bernoulli's equation, the pressure at the throat of the venturi-shaped test section falls as the velocity of the water increases. However, the pressure can only fall as far as the vapour pressure of the water at which point the water starts to vaporise - cavitation occurs. Any further increase in velocity cannot reduce the pressure below the vapour pressure, so the water vaporises faster - stronger cavitation occurs and Bernoulli's equation is not obeyed.



Figure 8.1: Cavitation Demonstration Unit

#### 8.5 Experimental procedure:

- 1. Place the equipment on hydraulic bench
- 2. Open the ball valve (right hand end) fully then close the inlet diaphragm valve (left hand end) fully.
- 3. Close the flow control valve on hydraulic bench. Switch on the hydraulic bench, then slowly open the flow control valve on hydraulic bench until it is fully open.
- 4. Slowly open the inlet diaphragm valve at the left hand end of cavitation apparatus and allow water to flow through the cavitation apparatus until the clear acrylic test section and flexible connecting tubes are full of water with no air entrained.
- 5. Continue to open the inlet diaphragm valve slowly until fully open to obtain maximum flow through the system. Note the milky formation at the throat indicating the presence of cavitation. Also note the loud audible crackling sound accompanying the cavitation.
- 6. Observe that the visible cavitation occurs in the expansion of the test section and not in the throat where the pressure is at its lowest (with the exception of the pressure tapping hole in the throat that causes a local disturbance to the flow).
- 7. If a thermometer is available measure and record the temperature of the water.

- 8. Close the inlet diaphragm valve until water flows slowly through the equipment with no cavitation in the test section (typically 0.1 Bar on the upstream gauge P1) ensuring that the test section remains full of water.
- 9. Record the following parameters: Upstream water pressure P<sub>1</sub> Bar.
  Pressure at the throat P<sub>2</sub> Bar (Vacuum).
  Downstream water pressure P<sub>3</sub> Bar.
- 10. Determine the flowrate by timing the collection of a known volume of water.
- 11. Gradually close the inlet diaphragm valve and observe that the Cavitation ceases as the pressure rises above the vapour pressure of the water (again there will be a long delay before the reading on the pressure gauge starts to fall because vapour inside the gauge is converting back to water).
- 12. Close the inlet diaphragm valve until water flows slowly through the equipment with no cavitation in the test section (typically 0.1 Bar on the upstream gauge  $P_1$ ) ensuring that the test section remains full of water.
- 13. For each set of readings calculate the volume flowrate, then plot the graph of P<sub>2</sub> against volume flowrate Q for each set of results.

#### 8.6 Observations & Calculations

Area of inlet section is  $= 150 \text{ mm}^2$ Area of narrow section (throat)  $= 36 \text{ mm}^2$ 

					-	-				
Obs.	∀ (l)	<i>t</i> ( <i>s</i> )	$Q(m^3/s)$	$P_1$ bar	$P_1/\gamma$	$P_2$ bar	$P_2/\gamma$	V <sub>1</sub> m/s	$V_2 m/s$	$V_1^2/2g$
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

#### Table 8.1: Calculation of vapour pressure at throat section

## 8.7 Specimen calculation

8.8 Conclusion:

### 9 LAB SESSION 9

To study the characteristics of the surface profile and angular velocity, and determine a relation between surface profile and total head for the free and forced vortex.

### 9.1 Learning Objectives:

At the end of this study, the student will be able to:

- Visualization of different vortices
- Investigation of free and forced vortices
- Representation of surface profiles
- Determination of velocity

#### 9.2 Apparatus

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Free and Forced Vortex Apparatus
- 2. Vernier Calliper
- 3. Scale
- 4. Hydraulic bench
- 5. Stop watch

#### 9.3 Main Parts of Free and Forced Vortex apparatus

- 1. Scale for measuring height
- 2. Point gauge with scale for measuring vortex radii
- 3. Free Vortex
- 4. Water drain
- 5. Valve for water drain
- 6. Point gauge for measuring height of the vortex surface

#### 9.4 Related theory

In fluid dynamics, a vortex is a circular flow of a fluid caused by sufficiently large velocity gradients. In practice, this can be observed when water flows out of a basin into a pipe or when two fluids with different speeds meet each other.

The experimental unit allows you to produce and study free and forced vortices.

The experimental unit has a transparent tank with nozzles, various inserts on the water drain, an impeller and a point gauge for detecting the vortex profiles. To form the free vortex, water is introduced radially into the tank and flows through a ring to slow down.

The vortex is created by the flow out of the tank. There are four easily replaceable inserts of various diameters available for the drain. To form a forced vortex, the water is introduced tangentially. The vortex is generated via an impeller driven by a water jet. The point gauges are used to measure the surface profiles of the vortices. The speed of the vortex is also determined. The experimental unit is positioned easily and securely on the work surface. Alternatively, the experimental unit can be operated by the laboratory supply. The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.



**Figure 9.1: Free and Forced Vortex Apparatus** 

#### 9.5 Experimental procedure:

- 1. Set up the equipment on the hydraulic bench so that its base is horizontal.
- 2. Surface of profile is determined by lowering the measure probes (needles) until they touch the surface of water.
- 3. Make sure that the water flow with the siphon effect by raising the hose to a standard before letting the water to the sink.
- 4. Measure the angular speed of the pedals by counting the number of circles in a certain time.
- 5. Record the vertical scale reading.
- 6. Repeat the experiment for various volumetric flow rates.

#### 9.6 Observations & Calculations

$$A = \frac{\pi}{4}D^2$$

$$D=10\ mm=0.01m$$

D =diameter at center

h = height of water surface above the datum

H = pitot tube differential head

X =pressure head/depth of the pitot tube

V = velocity of vortex

N = number of vortex revolutions

$$\omega = vortex$$
 angular velocity  $= \frac{2\pi N}{t}$ 

length of pitot tube 
$$= 15 mm$$

distance from reservoir center = 0, 30 mm, 50 mm, 70 mm, 90 mm, 110 mm

Surface profile for forced vortex can be represented by equation

$$z=\frac{\omega^2}{2g}r^2$$

Distribution of total head can be represented by equation

$$H=rac{\omega^2}{g}r^2$$
 $h=h_o+rac{\omega^2}{2g}r^2$ 

<b>Table 9.1:</b>	Calculation of	Volume	flow rate
-------------------	----------------	--------	-----------

Observation	Volume ∀ <sub>i</sub> ( <i>l</i> )	Time <b>t</b> ( <b>sec</b> )	Volume Flow rate $Q_i(l/s)$
1			
2			
3			
	$Q_{avg} = \frac{\sum Q_i}{3} =$	= l/s =	mm <sup>3</sup> /s

			0	rifice <b>1</b> ( <i>d</i>	= <b>24</b> <i>mm</i> )			
Obs.	<b>D</b> ( <b>mm</b> )	h (mm)	H (mm)	X (mm)	V(mm/s)	<i>r</i> ( <i>mm</i> )	$r^2(mm^2)$	$\frac{1}{r^2}(mm^2)$
1								
2								
3								
4								
5								
			0	rifice <b>2</b> ( <i>d</i>	= <b>16</b> <i>mm</i> )			
Obs.	<b>D</b> ( <b>mm</b> )	h (mm)	H (mm)	X (mm)	V(mm/s)	<i>r</i> ( <i>mm</i> )	$r^2(mm^2)$	$\frac{1}{r^2}(mm^2)$
1								
2								
3								
			(	Drifice 3 (d	= 8 mm)			
Obs.	<b>D</b> ( <b>mm</b> )	h (mm)	H (mm)	X (mm)	V(mm/s)	<i>r</i> ( <i>mm</i> )	$r^2(mm^2)$	$\frac{1}{r^2}(mm^2)$
1								
2								
3								

# 9.7 Specimen calculation

9.8 Conclusion:

## 10 LAB SESSION 10

To investigate the characteristics of flow through an orifice and to calculate the coefficient of discharge  $C_d$ , coefficient of velocity  $C_v$ , and coefficient of contraction  $C_c$  at a number of pressure heads for different orifices.

### **10.1 Learning Objective:**

At the end of this study, the student will be able to:

• Showing and determining the characteristics of a liquid flow through an orifice.

#### **10.2 Apparatus**

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Orifice Discharge Unit
- 2. Hydraulic bench
- 3. Stop watch
- 4. Orifices of various diameters

#### 10.3 Main Parts of orifice Discharge Unit

- 1. Cylindrical acrylic tank
- 2. Orifice
- 3. Inlet pipe
- 4. Overflow tube
- 5. Micrometre set
- 6. Pitot tube
- 7. Manometeric tubes

#### **10.4 Related theory**

The main component of this experimental apparatus is a cylindrical acrylic tank. Water enters the top of the tank and is distributed to the bottom of the tank through a diffuser. At the bottom of the cylinder, there is an orifice that allows water to flow down into the hydraulic bench below. There is also a tube connected at the base of the cylinder; the water level within this tube will be equal to that in the cylinder, hence the phrase, "water always finds its own level."

This equipment allows measurement of contraction and velocity coefficients as well as discharge coefficient for an orifice discharge. It is to be used with Hydraulics Bench. Water is admitted to the cylinder via a stainless steel wire mesh discharge head. An adjustable overflow allows various constant heads for the test. The orifice is fitted at the bottom of the cylinder flush with the base plate. A traverse assembly is provided below the cylinder. A blade and a Pitot tube are attached to this assembly.

The blade is to measure the jet diameter hence the Vena Contracta diameter and the Pitot tube is to measure the jet velocity. The velocity head on Pitot tube and total head due to tank water level are indicated on manometer tubes. The apparatus rests on adjustable footings and a bull's eye level is provided. The apparatus has a hose with a quick male coupling for connection to the Hydraulics Bench.



Figure 10.1: Orifice Discharge Unit

#### **10.5 Experimental procedure:**

- 1) Set up the apparatus on the Hydraulic Bench such that the orifice is facing the volumetric tank. Connect the hose from the inlet pipe to the bench supply. Make sure that the exit hose from the adjustable overflow pipe is positioned so that it will drain into the volumetric tank.
- 2) Turn the hydraulic bench on and allow water flow to enter the cylindrical tank. Adjust the flow until the water level in the tank is just above the black overflow tube within the cylinder.
- 3) Use the adjustable inlet pipe to position the diffuser just below the water level. For the best results, the level of the diffuser should always be adjusted to satisfy this condition.
- 4) Make sure there are no bubbles in the tube attached to the base of the cylinder and record the height of the water in that tube as  $H_0$ .



- 5) Without adjusting the flow rate of the water, make sure that no part of the experimental apparatus is impeding the flow of water exiting the base of the cylinder and collect water in the volumetric tank inside the hydraulic bench.
- 6) After the steady state is achieved, direct the water outlet hose into the bench volumetric tank. Collect water with a particular capacity (3 *l*,5 *l*, or 10 *l* for example) and record the time taken for the water to fill it up. Take at least 3 measurements and record the timings in order to calculate (average) volume flow rate.
- 7) Determine the velocity of the jet of water through the orifice by using continuity equation.
- 8) Move the Pitot tube into position directly underneath the exiting water jet while holding the flow rate into the cylinder constant.





- 9) Once the height of the water in the tube connected to the Pitot tube has stabilized, make sure there are no air bubbles in the hose and record this height as  $H_c$ . The difference between  $H_c$  and  $H_o$  may be small depending on the selected flow rate, though it is important to make the distinction between the two values.
- 10) Compute the actual velocity of the jet of water at the vena contracta.
- 11) Swing the micrometre so that the Pitot tube is in line with the jet and at a distance below the orifice approximately equal to the diameter of the orifice.
- 12) To measure the diameter of vena contracta, move the Pitot tube attached to the micrometre towards the water outlet from the orifice, touch the outer end of Pitot tube with water and read the value on micrometre then move the micrometre such that its inner end touches the water. To measure the diameter of vena contract subtract the value of Pitot tube diameter (4.5mm) from value taken from micrometer.



- 13) Slowly turn the micrometre knob until the blade starts touching the jet and record the micrometre reading.
- 14) Turn the micrometre knob until the blade start leaving the jet and again record the micrometre reading. Diameter of the Vena Contracta is the difference between the two manometer readings.
- 15) Compute the volume flow rate through the vena contracta.
- 16) Compute coefficient of velocity, coefficient of discharge and the theoretical and experimental coefficients of contraction.
- 17) Repeat the experiment for more water levels and flow rates.
- 18) Turn the flow bench off when the experiment is complete.
- 19) Plot a graph of cross sectional area against all the calculated coefficients for all the orifices.

#### **10.6 Observations & Calculations**

inner diameter of the all mouthpieces = Do = 24 mm.

cross sectional area of the orifice = 
$$A_0 = \frac{\pi}{A} D_0^2$$

diameter of the jet at vena contracta =  $D_C = 12$  mm.

cross sectional area of the jet at vena contracta = 
$$A_C = \frac{\pi}{4}D_C^2$$

actual discharge = 
$$Q_a = \frac{volume}{time} = \frac{\forall}{t}$$
  
ideal velocity =  $V_i = \sqrt{2gH_o}$ 

 $H_0$  = water head in the tank = vertical distance of water surface in the tank from orifice

ideal discharge = 
$$Q_i = A_o V_i = A_o \sqrt{2gH_o}$$
  
actual velocity =  $V_a = \sqrt{2gH_c}$ 

actual discharge throuh vena contracta =  $Q_c = A_c V_a = A_c \sqrt{2gH_c}$ 

$$C_{d} = \frac{Q_{c}}{Q_{o}} = \frac{Q_{c}}{A_{o}V_{o}}$$
$$C_{v} = \frac{V_{c}}{V_{o}} = \sqrt{\frac{H_{c}}{H_{o}}}$$
$$C_{c,exp} = \frac{C_{d}}{C_{v}}$$
$$C_{c,th} = \frac{A_{c}}{A_{o}} = \frac{D_{c}^{2}}{D_{o}^{2}}$$

$$X_{av} = \frac{1}{n} (x_1 + x_2 + x_3)$$
  
$$S_x = \sqrt{\frac{1}{n-1} ((x_1 - x_{av})^2 + (x_2 - x_{av})^2 + (x_3 - x_{av})^2)}$$

Observation	Volume $\forall_i (l)$	Time t (sec)	Volume Flow rate $Q_i(l/s)$
1			
2			
3			
	$Q_{avg} = \frac{\sum Q_i}{3} =$	= <i>l/s</i> =	mm <sup>3</sup> /s

#### Table 10.1: Calculation of Volume flow rate

### Table 10.2: Calculation of Cd, Cv, Cc for different orifices

				Orifice	$1 (D_o = 1)$	mm, A <sub>o</sub>	$= mm^{2}$ )					
Obs.	$Q_a$	H <sub>o</sub>	Vo	$Q_i$	H <sub>c</sub>	D <sub>c</sub>	$V_c$	$Q_{C}$	$C_{v}$	$C_d$	$C_{c,th}$	$C_{c,exp}$
	(l/s)	( <i>mm</i> )	(mm/s)	(l/s)	( <i>mm</i> )	( <i>mm</i> )	(m m/s)	(l/s)				-
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
	1		Orifice	$2(D_o =$	=	mm, A <sub>o</sub>	= <i>m</i>	.m <sup>2</sup> )	I		1	1
Obs.	Q <sub>a</sub>	H <sub>o</sub>	Orifice V <sub>o</sub>	$\frac{2(D_o = Q_i)}{Q_i}$	= <i>H<sub>c</sub></i>	mm, A <sub>o</sub> D <sub>c</sub>	= $mV_c$	2.m <sup>2</sup> ) Q <sub>C</sub>	Cv	C <sub>d</sub>	$C_{c,th}$	C <sub>c,exp</sub>
Obs.	$Q_a$ $(l/s)$	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice $V_o$ $(m m/s)$	$2 (D_o = Q_i)$ $Q_i$ $(l/s)$	= H <sub>c</sub> (mm)	$mm, A_o$ $D_c$ $(mm)$	$= m$ $\frac{V_c}{(m m/s)}$	$\frac{m^2}{Q_C}$ $(l/s)$	Cv	C <sub>d</sub>	C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs.	<i>Q</i> <sub>a</sub> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice $V_o$ (m m/s)	$2 (D_o = Q_i)$ $(l/s)$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	m <sup>2</sup> ) Q <sub>C</sub> (l/s)	Cv	C <sub>d</sub>	C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs. 1 2	<i>Q<sub>a</sub></i> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice $V_o$ $(m m/s)$	$2 (D_o = Q_i)$ $(l/s)$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	$\frac{m^2}{Q_C}$ $(l/s)$	Cv	C <sub>d</sub>	C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs. 1 2 3	<i>Q</i> <sub>a</sub> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice $V_o$ $(m m/s)$	$2 (D_o = Q_i)$ $(l/s)$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	$\frac{m^2)}{Q_C}$ $(l/s)$	<i>C</i> <sub>v</sub>	C <sub>d</sub>	C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs. 1 2 3 4	<i>Q<sub>a</sub></i> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice $V_o$ $(m m/s)$	$2 (D_o = Q_i)$ $(l/s)$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	$\frac{m^2)}{Q_C}$ $(l/s)$	<i>C</i> <sub>v</sub>	C <sub>d</sub>	C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs. 1 2 3 4 5	<i>Q<sub>a</sub></i> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice $V_o$ (m m/s)	$\frac{2 (D_o = Q_i)}{(l/s)}$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	$\frac{m^2)}{Q_c}$ $(l/s)$	<i>C<sub>v</sub></i>		C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs. 1 2 3 4 5 6	<i>Q<sub>a</sub></i> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice V <sub>o</sub> (mm/s)	$2 (D_o = Q_i)$ $(l/s)$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	$\frac{m^2)}{Q_C}$ $(l/s)$	<i>C<sub>v</sub></i>		C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs. 1 2 3 4 5 6 7	<i>Q<sub>a</sub></i> ( <i>l</i> / <i>s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice $V_o$ $(m m/s)$	$\frac{2 (D_o = Q_i)}{(l/s)}$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	$\frac{m^2)}{Q_c}$ $(l/s)$			C <sub>c,th</sub>	C <sub>c,exp</sub>
Obs. 1 2 3 4 5 6 7 8	<i>Q<sub>a</sub></i> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice V <sub>o</sub> (m m/s)	$2 (D_o = Q_i)$ $(l/s)$	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	$\frac{m^2)}{Q_C}$ $(l/s)$			C <sub>c,th</sub>	<i>C<sub>c,exp</sub></i>
Obs. 1 2 3 4 5 6 7 8 9	<i>Q<sub>a</sub></i> ( <i>l/s</i> )	<i>H</i> <sub>o</sub> ( <i>mm</i> )	Orifice V <sub>o</sub> (mm/s)	2 (D <sub>o</sub> = Q <sub>i</sub> (l/s)	= H <sub>c</sub> (mm)	mm, A <sub>o</sub> D <sub>c</sub> (mm)	$= m$ $V_c$ $(m m/s)$	m <sup>2</sup> ) Q <sub>c</sub> (l/s)			C <sub>c,th</sub>	<i>C<sub>c,exp</sub></i>

				Orifice	$3 (D_o = 1)$	mm, A <sub>o</sub>	$= mm^2$ )					
Obs.	$Q_a$	H <sub>o</sub>	$V_o$	$Q_i$	H <sub>c</sub>	$D_c$	$V_c$	$Q_{C}$	$C_v$	$C_d$	$C_{c,th}$	$C_{c,exp}$
	(l/s)	(mm)	(m m/s)	(l/s)	(mm)	(mm)	(m m/s)	(l/s)				
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
		r	Orifice	$4 (D_o =$	=	тт, А <sub>о</sub>	= m	$m^2$ )	I	I	n	
Obs.	$Q_a$	H <sub>o</sub>	Vo	$Q_i$	H <sub>c</sub>	D <sub>c</sub>	$V_{c}$	$Q_C$	$C_{v}$	$C_d$	$C_{c,th}$	$C_{c,exp}$
	(l/s)	( <i>mm</i> )	(m m/s)	(l/s)	(mm)	(mm)	(m m/s)	(l/s)				
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

	Orifice 5 $(D_o = mm, A_o = mm^2)$													
Obs.	$Q_a$	H <sub>o</sub>	$V_o$	$Q_i$	H <sub>c</sub>	$D_c$	$V_c$	$Q_C$	$C_v$	$C_d$	$C_{c,th}$	$C_{c,exp}$		
	(l/s)	(mm)	(mm/s)	(l/s)	(mm)	(mm)	(mm/s)	(l/s)						
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

## **10.7 Specimen Calculation**

# **10.8 Statistical Analysis**

 $C_d = C_v =$ 

 $C_c =$ 

**10.9 Conclusion:** 

## 11 LAB SESSION 11

To determine experimentally the volume flow rate by utilizing three basic types of flow meters including flow meter, Venturi meter and Orifice meter and comparing the results against the flow measurement by Volumetric Method through the hydraulics bench.

### **11.1 Learning Objectives:**

At the end of this study, the student will be able to:

- Calibration of flow meter
- Comparison of pressure drops across flowmeter

#### **11.2 Apparatus**

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Flow meter demonstration
- 2. Hydraulic bench
- 3. Stop watch

#### 11.3 Main Parts of Flow meter demonstration

- 1. Venturi meter
- 2. Variable area meter
- 3. Orifice plate
- 4. Manometeric tubes

#### **11.4 Related theory**

This apparatus consists of a flow bench that allows water flow to the measuring devices (venturi, wide-angled diffuser, orifice, elbow, and Rotameter).

The Flow Measurement Equipment contains different flow rate measurement devices that are clearly laid out with the associated pipework on a metal sheet. The measuring devices are made of transparent plastic, so that the function can be observed. The flow rate is measured using a nozzle, orifice, venturi flow meter and variable-area flow meter (Rota meter).

To determine the flow rate using a nozzle/orifice and with the venturi flow meter, a differential pressure measuring device is required. This is included in the form of a multiple tube manometer so that the pressure curve along the venturi flow meter can also be displayed. The apparatus is placed on the Basic Hydraulics Bench, which provides the water supply to the unit.

Flow meter Measurement Apparatus is designed to operate together with a basic hydraulic bench or any water supply. It is to familiarize the students with typical methods of flow measurement of an incompressible fluid.

The apparatus is able to demonstrate the flow measurement comparison by using a venturi device, orifice device and rotameter. The flow comparison can be further used to compare against the flow measurement by Volumetric Method through the hydraulics bench.



**Figure 11.1: Flow Demonstration Unit** 

#### **11.5 Experimental procedure:**

- 1) Set up the equipment on the hydraulic bench so that its base is horizontal. This is necessary for accurate height measurement from the manometer.
- 2) Check if the drain valve is open and keep it wide open and check whether the outlet pipe goes to the drain. Ensure that the rig outflow valve is positioned above the volumetric tank; in order to facilitate the timed volume collections.
- 3) Connect the rig inlet to the bench flow supply, close the bench valve and the apparatus flow control valve and start the pump. Initiate flow through the Venturi test section by gradually opening the inlet valve.

- 4) Check that all manometer tubes are properly connected to the corresponding pressure taps and are air-bubble free. If needed flush the air-bubbles by slowly closing the exit valve and draining the water (and the air-bubbles) through the manometer tubing.
- 5) Adjust both (inlet and outlet) valves so that the maximum difference in water levels between tapping point 1 and 3 is achieved.
- 6) Wait for some time for the level in manometer tubes to stabilize (it takes some time for it to reach steady state).
- 7) After the steady state is achieved, direct the water outlet hose into the bench volumetric tank. Collect water with a particular capacity (3 *l*,5 *l*, or 10 *l* for example) and record the time taken for the water to fill it up. Take at least 3 measurements and record the timings in order to calculate (average) volume flow rate.
- 8) Take static pressure head readings from all manometer tubes along the length of the Venturi meter.
- 9) Select any two cross sections and calculate the ideal volume flow rate through the venturi and compare the result with actual flow rate obtained from volumetric method.
- 10) Compute the co-efficient of discharge for the flow through venturi.
- 11) Take static pressure head readings from all manometer tubes along the length of the Orifice meter.
- 12) Select the inlet and the outlet cross sections for the flow through orifice and calculate the ideal volume flow rate through the orifice and compare the result with actual flow rate obtained from volumetric method.
- 13) Compute the co-efficient of discharge for the flow through orifice.
- 14) Measure the volume flow rate through the Rota meter by carefully observing the position of the floating vessel. For this particular Rota meter, read the float position at the largest diameter.
- 15) Compute the co-efficient of discharge for the flow through Rota meter.
- 16) Make 10 runs, being sure measure and calculate flow rate, and repeat the calculations.
- 17) Plot a graph between flow rates measured through volumetric method and Venturi meter.
- 18) Plot a graph between flow rate measured through volumetric method and  $C_d$  for flow through Venturi.
- 19) Plot a graph between flow rates measured through volumetric method and Orifice meter.
- 20) Plot a graph between flow rate measured through volumetric method and  $C_d$  for flow through Orifice.
- 21) Plot a graph between flow rates measured through volumetric method and Rota meter.
- 22) Plot a graph between flow rate measured through volumetric method and  $C_d$  for flow through Rota meter.

23) Plot graph between flow rate measured through volumetric method against the flow rate measured through Venturi meter, Orifice meter and Rota meter respectively, and show the results on the same graph.

#### **11.6 Observations & Calculations**

actual discharge through venturi = 
$$Q_a = \frac{\forall}{t}$$

$$A_i = \frac{\pi}{4}D_i^2$$

head of water in piezometer tubes =  $h_i(h_A, h_B, h_C, h_D, h_E, h_F)$ 

 $h_1 - h_2 =$  differential head in any two piezometer tubes, selected to measure discharge

ideal discharge through venturi = 
$$Q_i = A_2 \sqrt{\frac{2(p_1 - p_2)}{\rho \left[1 - \left(\frac{A_2}{A_1}\right)^2\right]}} = A_2 \sqrt{\frac{2g(h_1 - h_2)}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

$$P = \gamma . h$$

coefficient of discharge = 
$$C_d = \frac{Q_a}{Q_i}$$

Assumption:

 $C_D = 0.98$  for Venturi meter

 $C_D = 0.63$  for the Orifice plate

#### **Calculation of Volume Flowrate**

Venturi Meter



$$D_{1} = 32 \text{ mm}, \qquad D_{2} = 20 \text{ mm}, \qquad D_{3} = 32 \text{ m}$$

$$V_{B} = \sqrt{\frac{2g(h_{A} - h_{B})}{1 - \left(\frac{A_{B}}{A_{A}}\right)^{2}}} = \sqrt{\frac{2g(h_{A} - h_{B})}{1 - \left(\frac{d_{B}}{d_{A}}\right)^{4}}}$$

$$Q_{venturi} = A_{B}V_{B} = A_{B}\sqrt{\frac{2g(h_{A} - h_{B})}{1 - \left(\frac{A_{B}}{A_{A}}\right)^{2}}} = A_{B}\sqrt{\frac{2g(h_{A} - h_{B})}{1 - \left(\frac{d_{B}}{d_{A}}\right)^{4}}}$$

#### **ORIFICE METER**



 $D_{G} = 35 \text{ mm}, \qquad D_{H} = 19 \text{ mm}$   $\frac{P_{E}}{\rho} + \frac{V_{E}^{2}}{2} = \frac{P_{F}}{\rho} + \frac{V_{F}^{2}}{2} + h_{l}$   $\frac{V_{F}^{2}}{2} - \frac{V_{E}^{2}}{2} = K^{2} \left(\frac{P_{E}}{\rho} - \frac{P_{F}}{\rho}\right)$  K = 0.601  $Q_{orifice} = A_{F}V_{F} = A_{F}K \sqrt{\frac{2g(h_{E} - h_{F})}{1 - \left(\frac{A_{F}}{A_{E}}\right)^{2}}} = A_{B}K \sqrt{\frac{2g(h_{E} - h_{F})}{1 - \left(\frac{d_{F}}{d_{E}}\right)^{4}}}$   $V_{F} = K \sqrt{\frac{2g(h_{E} - h_{F})}{1 - \left(\frac{d_{F}}{d_{E}}\right)^{4}}} = K \sqrt{\frac{2g(h_{E} - h_{F})}{1 - \left(\frac{A_{F}}{A_{E}}\right)^{2}}}$ 

Venturi Meter											
Obs.	$h_i(mm)$				$h_1 - h_2$	$A_{2}/A_{1}$	¥	t	$Q_a$	$Q_i$	$C_d$
	$h_A$	$h_B$	$h_{C}$		(mm)		(l)	<i>(s)</i>	(l/s)	(l/s)	
1											
2											
3											
4											
5											

### Table 11.1: Calculation of Volume flow rate and $C_{\rm d}$

Orifice Meter										
Obs.	$h_i(mm)$		$h_1 - h_2$	$A_{2}/A_{1}$	¥	t	$Q_a$	$Q_i$	$C_d$	
	$h_A$	$h_B$	(mm)		(l)	<i>(s)</i>	(l/s)	(l/s)		
1										
2										
3										
4										
5										

Obs.	¥	t	$Q_a$		$C_d$		
	<i>(l)</i>	<i>(s)</i>	(l/s)	(GPM)	(LPM)	(l/s)	
1							
2							
3							
4							
5							

# **11.7 Specimen calculation**
11.8 Conclusion:

# 12 LAB SESSION 12

To observe the subduing of the water hammer effects.

### **12.1 Learning Objectives:**

At the end of this study, the student will be able to:

- To observe the subduing in function of the diameter of the chimney
- To calculate the energy losses in pipes

#### **12.2 Apparatus**

In order to complete the experiment, we need a number of pieces of equipment.

- 1. Water hammer Apparatus
- 2. Hydraulic bench
- 3. Stop watch

#### 12.3 Main Parts of Water Hammer apparatus

- 1. Chimney
- 2. Level tank
- 3. Impact valve
- 4. Structure of anodized aluminium

#### **12.4 Related theory**

When closing a valve abruptly the liquid which is nearest to the end of a pipe coming from a storage tank in the instant t = 0 is compressed at the same time that its movement decreases to zero. Under these conditions the walls of the pipe suffer an expansion. Liquid continues moving up to the end keeping the same speed, until it is reached by the compression effect.

We have different ways to reduce the water hammer effect. The elements that are being used to reduce or eliminate the water hammer depend on the diameter of the pipe and flow of the equipment. For small diameter pipes used in impellers, water supplies, etc. coarse with having relief valves of diverse types, which are available in the market. In case of big diameter pipes, which are common in hydraulic works, the balance chimney is used.



Figure 12.1: Situation in which the impact valve and the pump are opened



Figure 12.2: Situation in the chimney once introduced the water hammer



Figure 12.3: Water Hammer apparatus

## 12.5 Conclusion: