GERMAN JORDANIAN UNIVERSITY

SCHOOL OF NATURAL RESOURCES ENGINEERING AND MANAGEMENT

WATER AND ENVIRONMENTAL ENGINEERING DEPARTMENT

Water and Environmental Hydraulics Laboratory

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SAFETY

The following practices will be exercised in the laboratory:

1. On laboratory days, long pants must be worn, and shoes must be closed-toe (no sandals). If students dressed inappropriately, they will be asked to change before the beginning of the experiment. If not, they will be prohibited from the conducting the experiment and will lose marks based on that.
2. You are to bring only your manual, calculator and pen into the lab. Your back bags, hand bags will all be gathered away and not allowed to be put on the lab benches
3. Smoking, eating or drinking are not allowed in the laboratory. GUM chewing is included!
4. Cell phones are to be shut down during the lab, or they will be confiscated during other labs for students who break the rule.
5. Report all injuries and accidents to the instructor or TAs immediately, no matter how minor.
6. Each student is responsible of cleaning his/her station all the time. Marks will be deducted from your work if the station and glassware were left dirty.

AGREEMENT

SIGN AND DATE THIS AS A REMINDER OF PROCEDURES YOU WILL BE PRACTICING DURING HYDRAULICS LAB.

- I have read and agree to follow all of the safety rules set forth in this contract. I realize that I must obey these rules to insure my own safety, and that of my fellow students and instructors. I will corporate to the fullest extent with my instructor and fellow students to maintain a safe lab environment. I will also closely follow the oral and written instructions provided by the instructor. I am aware that any violation of this safety contract that results in unsafe conduct in the laboratory or misbehavior on my part may result in being removed from the laboratory.

No.	Student Name	Reg. No.	Date	Signature

THIS IS A COPY OF THE AGREEMENT YOU WILL HAVE TO SIGN BEFORE WORKING IN WEEM LABS.

Bring:
Notebook
Calculator
Lab Coat
Lab Manual
Pen

Introduction

This guide is designed to be used in preparing laboratory reports for all courses. Though, this guide contains useful information can be used in writing any engineering laboratory report.

This guide describes the structure of a good engineering report, explain the need for each section, and outlines the contents for these sections. It introduces some standard conventions and rules for writing reports of professional quality. Reports will be reviewed on the basis of instructions contained in this document, and grades will be strongly affected by the quality of reports.

Laboratory Notebook

An essential requirement of engineering experimentation is that a laboratory notebook be maintained. This notebook should contain dated entries for every laboratory session, which include all the notes and sketches made during the session, all the data recorded, and any other observation relevant to the laboratory session. Professional engineers and scientist should make it a standard practice to maintain such notebooks. There are several reasons to do so. A complete and updated notebooks permit easy access to information, eliminates bias in recording and interpreting data, establishes a time line that is vital for patent applications, and helps in preparation of reports.

Every student is required to maintain a laboratory notebook. The following systems will be adopted in each laboratory course: Students maintain one laboratory notebook. At the end of each session, the student shows the book to the TA (Teaching Assistance), who inspects it, make any necessary suggestions for improvement, and records the inspection on a grade sheet. The student turns in the notebook for final evaluation with the last report in the semester.

Structure of Engineering Reports

Engineering reports may be classified according to whether they are complete engineering reports on a project, short reports on one or more tests, or short reports on one or more techniques. The structure of engineering reports has evolved to serve the needs of the varied readership. For more information about the evolution of engineering reports consult Tuve and Domholdt (1966).

Engineering report should always be written for the convenience of the reader. Thus, for example each section of the report should be headlined and the sections should be arranged in an appropriate easily-understood sequence. In the context of the course for which it is written, the laboratory report serves to describe what you did during the laboratory session, how you manipulated the raw data, and what your conclusions are. While it may seem logical to you to write a report in chronological or historical sequence, such an approach is not the most useful for your readers, who would find such a report difficult to scan for the items of interest. Think of the document as proof that you understand what you did and that you can apply it in practical situations. It is a performance document.

By the time you take several laboratory courses, you are expected to understand both format for a full engineering report and some of the variations that are appropriate in different contexts. The engineering reports described above typically contain several (but not necessarily all) of the following sections, in the order listed:

1. Title Page
2. Table of Contents
3. Introduction (Background Information)
4. Statement of Objectives
5. List of Equipment used
6. Procedure
7. Data
8. Analysis of Data
9. Discussion of Results
10. Conclusions
11. Recommendations
12. References

Content of Report Sections

The content of each of the sections in an engineering report is described in the following pages. Most of the descriptions are general enough to be valid for all engineering reports.

1. Title page

Information on the title page should be balanced and centered neatly. It should consist of

- A brief but informative title that describes the report
- The name (s) of the author
- The dates (s) the experiment was performed, and the date the report was due
- The laboratory section number and the name of the Teaching Assistant
- The names of other group members who were present for the experiments

2. Table of Contents

A table of contents should be placed following the title page if the report is long (more than ten pages). It should list each section of the report and the corresponding page number.

3. Introduction and Background Information

The appropriate information for the introduction varies with the kind of report. Most introductions provide the reader with the necessary background to help put the objectives and results in a proper perspective. When necessary, previous related work is described. If the report is on several short experiments, the overall purpose and background of the group of experiments should be described first, followed by the necessary information for group of experiments should be described first, followed by the necessary information for each of the experiments. In this case, the introduction should not be a mere collection of material on each, but should be written using connected paragraphs with clear transitions between ideas and information.

4. Statement of Objective

State the objective (s) of the experiment concisely, in paragraph form. The laboratory manual or instruction sheet will help here. The fact that experiments in laboratory courses are being used to educate students is a secondary objective, and should not be stated in the report. The section should inform the reader precisely why the project was undertaken.

5. List of Equipment Used

List all the equipment and materials used in the experiment. Include identifying marks (usually serial numbers) of all equipment. This is a safeguard that allows you to trace faulty equipment at a later date, if necessary. The reader must be able to connect each item in this section to the item in the Description of Experimental Setup section.

6. Procedure

Detail the procedure used to carry out the experiment step. The laboratory manual of instruction sheet, together with the instructions given to you by the laboratory instructor, will be of help here. Sufficient information should be provided to allow the reader to repeat the experiment in an identical manner. Special procedures used to ensure specific experimental conditions, or to maintain a desired accuracy in the information obtained should be described.

7. Data

All the pertinent raw data obtained during the experiment are presented in the section. The type of data will vary according to the individual experiment, and can include numbers, sketches, images, photographs, etc. All numerical data should be tabulated carefully. Each table, figure and graph in report must have a caption or label and a number that is referenced in the written text. Variables tabulated or plotted should be section should contain only raw information, not results from manipulation of data. If the latter need to be included in the same table as the raw data in the interests of space or presentation style, the raw data should be identified clearly as such.

8. Analysis of Data

This section describes in textual form how the formulaic manipulation of the data was carried out and gives the equations and procedures used. If more than one equation is used, all equations must carry sequential identifying numbers that can be referenced elsewhere in the text. The final results of the data analysis are reported in this section, using figures, graphs, tables or other convenient forms. Sample calculations and details of calculations and analyses should be placed in the Appendix, and the reader directed to the appropriate section of the Appendix for that information. The end result of the data analysis should be information, usually in the form of tables, charts, graphs or other figures that can be used to discuss the outcome of the experiment or project. This section must include statements about the accuracy of the data, supported where necessary by an error analysis. Details of the error analysis are to be included in the Appendix.

9. Discussion of Results

This section is devoted to your interpretation of the outcome of the experiment or project. The information from the data analysis is examined and explained. You should describe, analyze and explain (not just restate) all your results. This section should answer the question what do the data tell me? Describe any logical projections from the outcome, for instance the need to repeat the experiments or measure certain variables differently. Assess the quality and accuracy of your procedure. Compare your results with expected behavior, if such a comparison is useful or necessary, and explain any unexpected behavior.

10. Conclusions

Base all conclusions on your actual results. Explain the meaning of the experiment and the implications of your results. Examine the outcome in the light of the stated objectives. Seek to make conclusions in a broader context in the light of the results.

11. Recommendations

This section is sometimes combined with the conclusions to make the report more readable. The section should address extensions, changes or modifications of future experiments and the reasons why these suggestions are made. Several issues can be raised Do the results suggest the need for other experiments? If so, what are the new objectives? Is the present procedure inadequate or incorrect? If so, how should it be changed? Does it call for a different technique of different instrument? Is the objective itself reasonable?

17. References

Using standard bibliographic format (see Hacker, 1992), cite all the published sources you consulted during the conduct of the experiment and the preparation of your laboratory report. List the author (s) title of paper or book, name of journal, or publisher as appropriate, page number (s) if appropriate and the date. If a source is included in the list of references, it must also be referred to at the appropriate place (s) in the report.

Language and Style

As with all other modes of communication, engineering reports are most effective if the language and style are selected to suit the background of the principal readers. Engineering reports are judged not only on the technical content, but only clarity, ease of understanding, word usage and grammatical correctness. Making an effort to improve your writing will pay off in better grades and in your professional advancement after graduation.

Reports should be written in the ***third person, past tense, in an impersonal style***. The entire report should be written in textual form; don't expect figures or equations to serve where sentences and paragraphs are needed. As you edit your report, delete unnecessary words, rewrite unclear phrases and clean up grammatical errors. Use separate headings for each section. Allow space between sections. Place tables, schematics, or graphs logically, label and number them clearly, and execute them neatly. Aim for a clear, easy-to-read, professional-looking report.

References

Hacker, D. A Writer's Reference, Bedford Books of St. Martin's Press. Inc., Second edition, 1992.

Tuve, G. L., and Domholdt, L. C., Engineering Experimentation, McGraw-Hill Book Company, 1966.

Acharya, M., Bergmann, L. and Way, J., A Guide to Laboratory Report Writing, Illinois Institute of Technology, 1993.

INTRODUCTION

Hydraulics has developed as an analytical discipline from the application of the classical laws of statics, dynamics and thermodynamics, to situations in which fluids can be treated as continuous media.

The particular laws involved are those of conservation of mass, energy and momentum and in each application, these laws, may be simplified in an attempt to describe quantitatively the behavior of the fluid.

The materials of this manual have been written to describe fluid mechanics, and hydraulic instruments, components, and theoretical background, to employ all of those materials for engineering applications through a demonstrated work.

We hope this manual would provide the students with the necessary knowledge, to demonstrate a particular aspect of the fluid mechanics and hydraulics theories.

(1) Fluid Properties
(Specific Gravity, Density and Viscosity)

1. 1 Specific Gravity and Density

Objective:

To determine the specific gravity and density of some liquids (i.e. Diesel Oil, Glycerol and Castor Oil) at certain atmospheric pressure and temperature

. Theory:

A hydrometer is an instrument used to measure the specific gravity (or relative density) of liquids; that is, the ratio of the density of the liquid to the density of water, based on **Buoyant principle**. A hydrometer is usually made of glass and consists of a cylindrical stem and a bulb weighted with mercury or lead shot to make it float upright. The liquid to be tested is poured into a tall container, often a graduated cylinder, and the hydrometer is gently lowered into the liquid until it floats freely. The point at which the surface of the liquid touches the stem of the hydrometer is noted. Hydrometers usually contain a scale inside the stem, so that the specific gravity can be read directly.

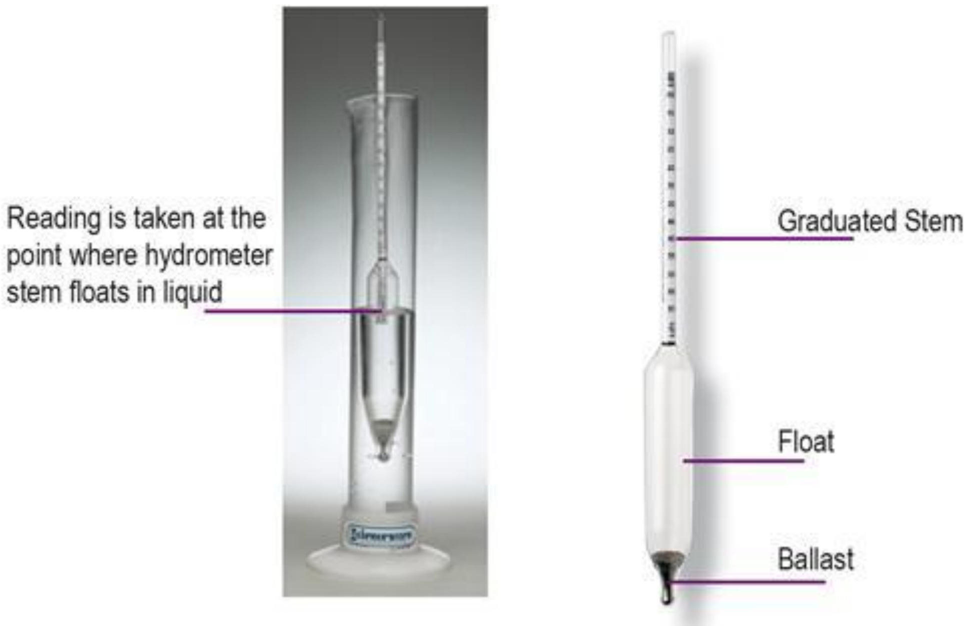


Figure1 (hydrometer)

Consider the hydrometer is placed in distilled water (S.G=1.00), Newton Law of motion for the hydrometer under equilibrium can be written as:

F_B - W = 0 ....(1)

γ_w* $V_\circ$ –W = 0 ....(2)

-Where:

$F_{B=}$ Buoyant force on the hydrometer (upward)

W= Weight of the hydrometer (downward)

γ_w=Specific weight of water

When the same hydrometer is placed in any other liquid, equation (1) can be written as:

γ_l* ($V_\circ$ ± ΔV) - W = 0 ....(3)

-Where:

γ_l=Specific weight of the liquid

Combining equations (2) & (3) yields:

γ_w* $V_\circ$ - γ_l* ($V_\circ$ ± ΔV) = 0 ....(4)

After simplification, the Specific Gravity of the liquid is given by :

$$\gamma_l / \gamma_w = \mathbf{V_\circ/(V_\circ \pm \Delta V) = S.G_l}$$

But $\gamma_{l} = \rho_l * g$

$\gamma_{w} = \rho_w * g$

-Where:

g = gravitational acceleration

ρ_l, ρ_w= density of liquid and water consequently

Hence, we can write the specific gravity equation as:

$$\rho_l = S.G_l * \rho_w$$

Apparatus & Materials:

-Universal Hydrometer

-Graduated Cylinders

-Liquids: distilled water, diesel oil, glycerol and castor oil.

Procedure:

1. Fill the precipitate tube or cylinder with water in such a way that the hydrometer floats.

Check that the submerged length corresponds to 1.00 in the graduated scale.

2. Fill the other three cylinders with the liquids to work with, and note down the scale mark for each one.

This value in the scale indicates the specific gravity.

LAB SHEET (Density)

Calculations and Results:

Write down the results obtained in the following table, taking into account the values of the atmospheric pressure and temperature in the moment of performing the practice.

Barometric Pressure .... mm Hg
Temperature... º C

Liquid	Specific Gravity	Density(g/cm^3)	Universal Value(g/cm^3)
Water			**1**
Diesel Oil			.82-.92
Glycerol			**1.12**
Castor Oil			**.956**

Note: 1g/ml = 1000 Kg/m^3

$\rho_w = 1\ g/cm^3 = 1\ g/ml = 1000\ Kg/m^3$

Issues to be considered in your report:

What are the potential sources of error in the experiment? How could they be overcome?..
....
....

What is the relation between atmospheric pressure, temperature and density?..
....
....

Compare Laboratory results to universal ones.
………
………
………
………………….…

1.2 Viscosity

Objective:

To determine the viscosity of some liquids (i.e. Diesel Oil, Glycerol and Castor Oil) at certain atmospheric pressure and temperature.

Theory:

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid. A fluid with large viscosity resists motion because its molecular makeup gives it a lot of internal friction. A fluid with low viscosity flows easily because its molecular makeup results in very little friction when it is in motion.

Consider a spherical steel **ball** falling freely through a liquid as shown in the fig.2. After certain time, after the falling ball is moving with a uniform velocity u, thus forces acting on the sphere are: -

(a) Gravitational force on the ball Ws (acting downward

(b) Buoyant force, F_B(acting upward).

(c) Viscous or drag force resulted from friction between the ball and the liquid, Fv (upward)

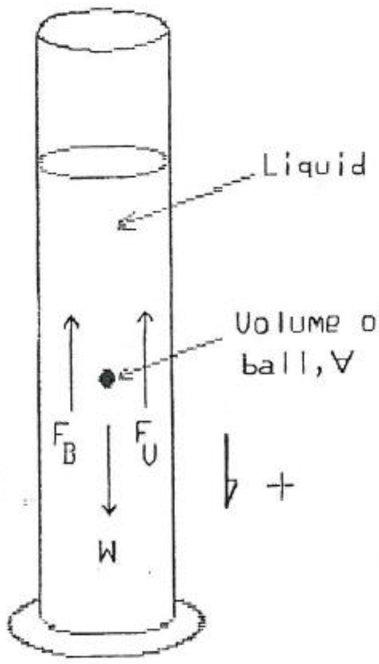


Fig. 1-2

Figure2(a spherical steel ***ball*** falling freely through a liquid)

Because of the uniform falling velocity, Newton 2nd law can be written for the falling ball as:

$W_s - F_B - F_v = 0$ ……………..(1)

$W_s = m_s*g = \rho_s * V_s * g = \rho_s * 4/3 * \pi * r^3 * g$ ..……………(2)

$F_B = \gamma_l * V_s = \rho_l * V_s * g = \rho_l * 4/3 * \pi * r^3 * g$ ……..………(3)

-Where:

r = sphere radius

ρ_s = sphere density

V_s = sphere volume

$\rho_{l=liquid}$ density

μ= liquid **Dynamic** viscosity, also called **Absolute** viscosity

u= liquid velocity

For Reynolds number less than 0.3 (Laminar Flow), Stokes Law for falling particle gives:

$F_v = 6*\mu*\pi*r*u$ ……………(4)

Substituting equations (2,3 and 4) into equation (1) gives:

$\rho_s * 4/3 * \pi * r^3 * g - \rho_l * 4/3 * \pi * r^3 * g - 6*\mu*\pi*r*u = 0$

Hence, the Dynamic Viscosity can be calculated:

$$\mu = 2/9 * r^2 * g * (\rho_s - \rho_l)/u$$

* Units: Poise = 0.1 Pa.s = 0.1 Kg/m.s

Also, the Kinematic Viscosity (*ν*) can be calculated:

$$\nu = \frac{\mu}{\rho}$$

* Unit: Stokes = 10^{-4} m^2/s

Apparatus & Materials:

-Stop watch

-Graduated Cylinders

-Liquids: distilled water, diesel oil, glycerol and castor oil

- 3 spherical steel balls (2, 3, 4) mm diameters

- Scale

Procedure:

1. Throw a ball of known diameter and specific gravity in each graduated cylinder containing: Diesel Oil, Glycerol and Castor Oil.

2. Write down the time used by the ball to go down the cylinders, using a stop watch.

3. Repeat steps 1 & 2 with balls of different diameters.

LAB SHEET (Viscosity)

Calculations and Results:

Write down the existing atmospheric pressure and temperature in that moment in the laboratory. With the aid of the data and expressions given hereafter, complete the following table:

Pressure .... mm Hg
Temperature .... º C

Measured diameters of balls= (2 , 3 , 4)mm

Density of steel= 7.8 g/cm3

Liquids: Diesel Oil, Glycerol, Castor Oil

Cylinder diameter = 64mm

Diesel Oil:

Ball Diameter (m)	Time (s)	Travel Distance (m)	Falling Velocity (m/s)	μ (Pa.s)	*v* (m/s^2)

Glycerol:

Ball Diameter (m)	Time (s)	Travel Distance (m)	Falling Velocity (m/s)	μ (Pa.s)	*v* (m/s^2)

Castor Oil:

Ball Diameter (m)	**Time (s)**	**Travel Distance (m)**	**Falling Velocity (m/s)**	**μ (Pa.s)**	***v* (m/s^2)**

Issues to be considered in your report:

-What are the potential sources of error in the experiment? How could they be overcome?...
....

-What is the relation between atmospheric pressure, temperature, density and viscosity?...
....
....

Compare Laboratory results to universal ones
………
………
………
-…………………

(2) Center of Pressure on a Plane surface

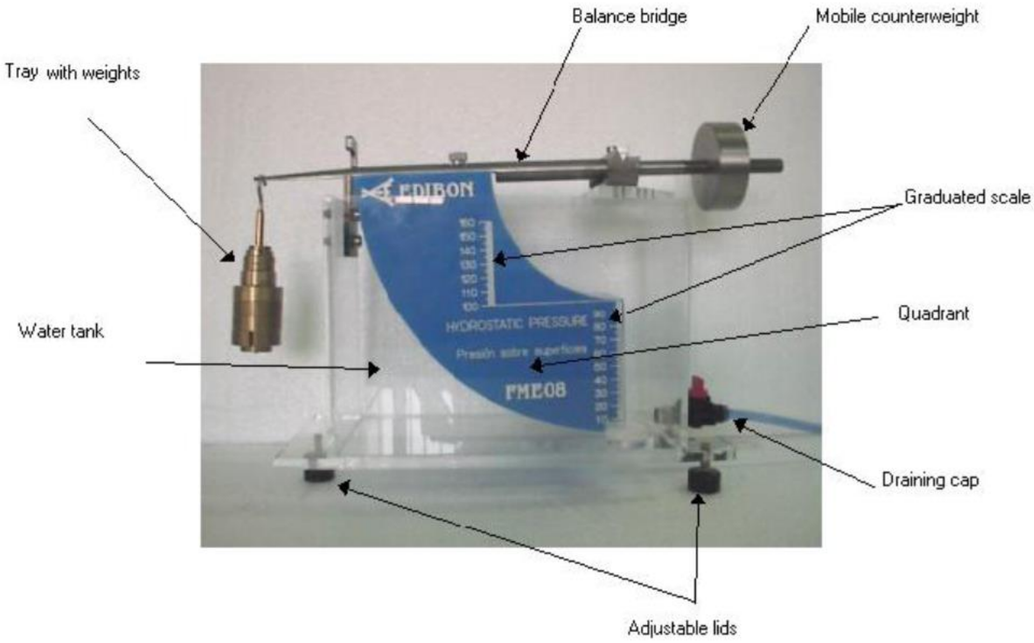


Figure2.1: Center of pressure apparatus

Objective:

Determine the force exerted by the fluid on a rectangular surface; called Hydrostatic Force (magnitude and location) for both partially and fully immersed cases.

Theory:

A body immersed, either partially or fully in a fluid at a static condition has a force exerted on it by the fluid. This force which is called "Hydrostatic Force" has many beneficial uses, for example: design of sluice gates, dams or other hydraulic structures.

Consider a plate of area (A) immersed in a fluid of specific weight (γ_l) and inclined by θ from the horizontal. Making the axis as shown in Fig.(2-2) and by taking an infinitesimal area (δA) as shown, δF exerted on that area is:

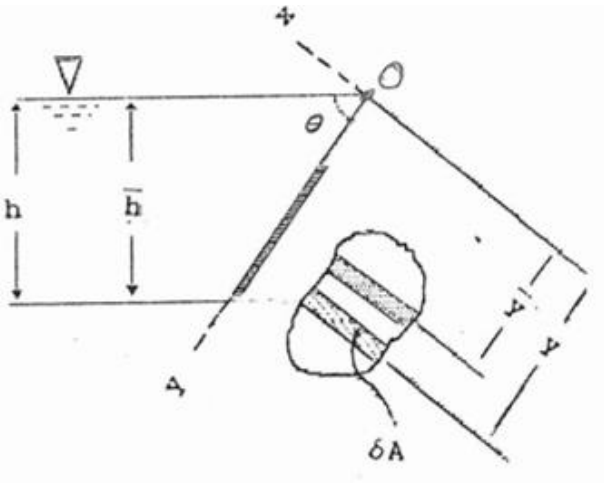


Figure2.2:body diagram

$\delta F = p * \delta A$ ……….…….(1)

-where:

P = hydrostatic pressure at depth (h)

But:

$p = \gamma_l * h = \gamma_l * y * \sin\theta$ …….……..…(2)

then:

$\delta F = \gamma_l * y * \sin\theta * \delta A$ ……..………(3)

After integration of equation (3) over the whole area (A), it gives:

$F = \gamma_l * \sin\theta * \int_A y\ \delta A$

But by Mean Value Theorem:

, where $\bar{y}$ *is the center of area* $\int_A y * \delta A = \bar{y} * A$

Therefore, $\mathbf{F = \gamma_l * \sin\theta * \bar{y} * A}$ ….…..………(4)

To find the point of action of the force (F); i.e. center of pressure y_{cp}, take the moment around "o" as:

$y_{cp} * F = \int_A y * \delta F$

Or using equation (3):

$y_{cp} * F = \int_A y * \gamma l * y * \sin\theta\ \delta A$

$= \int_A y^2 * \gamma l * \sin\theta\ \delta A$

But

$\int_A y^2\ \delta A = I$ where I is second moment of inertia about "o"

Also, by parallel axis theorem:

$I = I_{CG} + \bar{y}^2 * A$

Where: I_{CG} is the 2nd moment of inertia around the center of gravity.

Hence:

$y_{cp} * F = \gamma_l * \sin\theta * (I_{CG} + \bar{y}^2 * A)$ ……………..(5)

After using equation (4), equation (5) simplifies to:

$\mathbf{ycp = \bar{y} + \frac{ICG}{\bar{y} * A}}$ ……………..(6)

Distribution of pressures:

In the figure 2.3, we can see that the distribution of pressures over surfaces that are not flat does not cause any momentum in relation to the turning axle (because they are in the radial direction to this one, Pr1 and Pr2). The distribution of pressures in the frontal side (side with graduated scale) is equal and with opposite direction to the rear side (opposite side to the graduated scale). In conclusion, the only surfaces that causes a momentum in relation with the turning point "***O***" will be the flat one (Pp).

Partial Immersion case:

For a torriod rectangular surface on the vertical position (θ =90°)

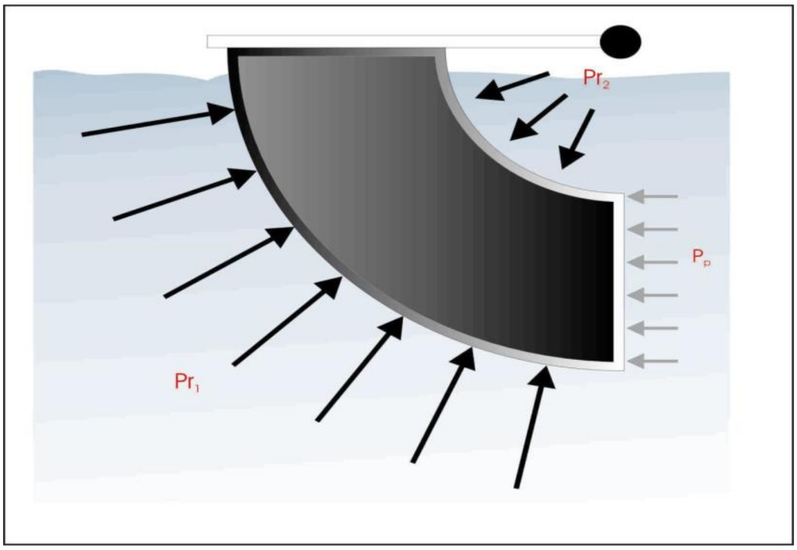


figure2.3 pressure distribution

22

I. The magnitude of the hydrostatic force:

*Using Equation (4)

$F = \gamma_l * \sin 90 * \bar{y} * A$

$= \gamma_w * \frac{y}{2} * b * y$

II. Center of Pressure:

* Using Equation (6)

$I_{CG} = \frac{b * y^3}{12}$

$ycp = \frac{y}{2} + \frac{\frac{b * y^3}{12}}{\frac{y}{2} * b * y}$

$= 2/3 * y$

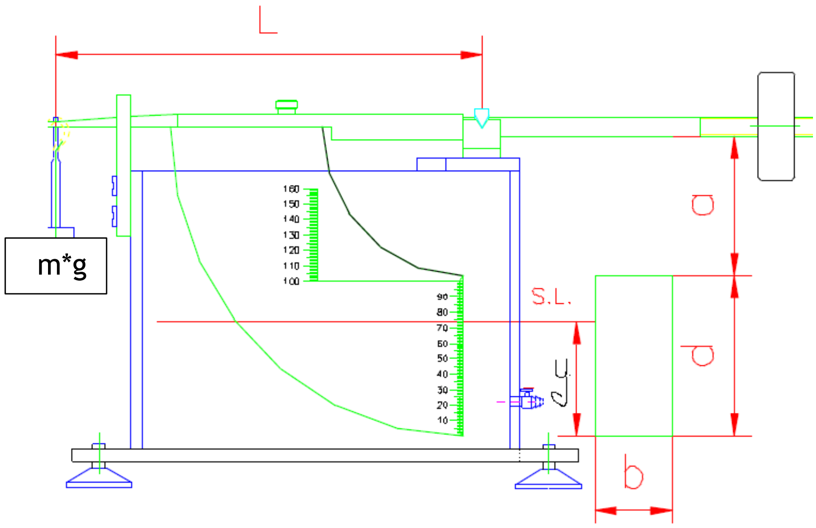


Figure. 2.4

Taking the moment around the pivot as shown in Fig. 2.4

$m * g * L = F * \bar{y}_{cp}$

Where: $\bar{y}_{cp}$ is the center of pressure from beam level (i.e. pivot level)

$\bar{y}_{cp} = a + d - y_{cp} = a + d - 1/3 * y$ (from Fig. 2.3)

Hence:

$m * g * L = \gamma_w * \frac{y^2}{2} * b * (a + d - 1/3 * y)$

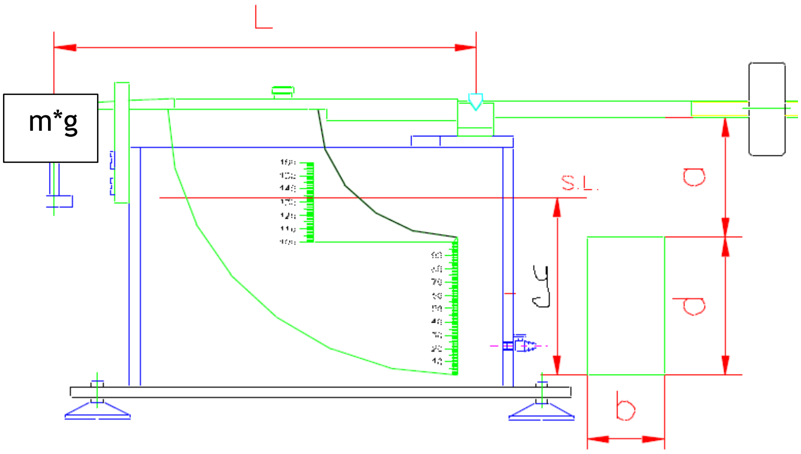
Full Immersion Case:

For a torriod rectangular surface on the vertical position (θ =90°)

I. The magnitude of the hydrostatic force:

*Using Equation (4)
$F = \gamma_l * \sin 90 * \bar{y} * A$

$= \gamma_w * \left(y - \frac{d}{2}\right) * b * d$



II. Center of Pressure:

* Using Equation (6)

$I_{CG} = \frac{b * d^3}{12}$

$ycp = (y-d/2) + \frac{\frac{b * d^3}{12}}{\left(y-\frac{d}{2}\right) * b * d}$

$ycp = (y-d/2) + \frac{d^2}{12 * \left(y-\frac{d}{2}\right)}$

Taking the moment around the pivot as shown in Fig. 2.4

$m * g * L = F * \bar{y}_{cp}$

$\bar{y}_{cp} = a + d/2 + (y_{cp} - \bar{y}) = a + d/2 + \frac{d^2}{12 * (y - \frac{d}{2})}$ (from Fig. 2.4)

Hence:

$m * g * L = \gamma_w * \left(y - \frac{d}{2}\right) * b * d \left(a + d/2 + \frac{d^2}{12 * (y - \frac{d}{2})}\right)$

Apparatus:

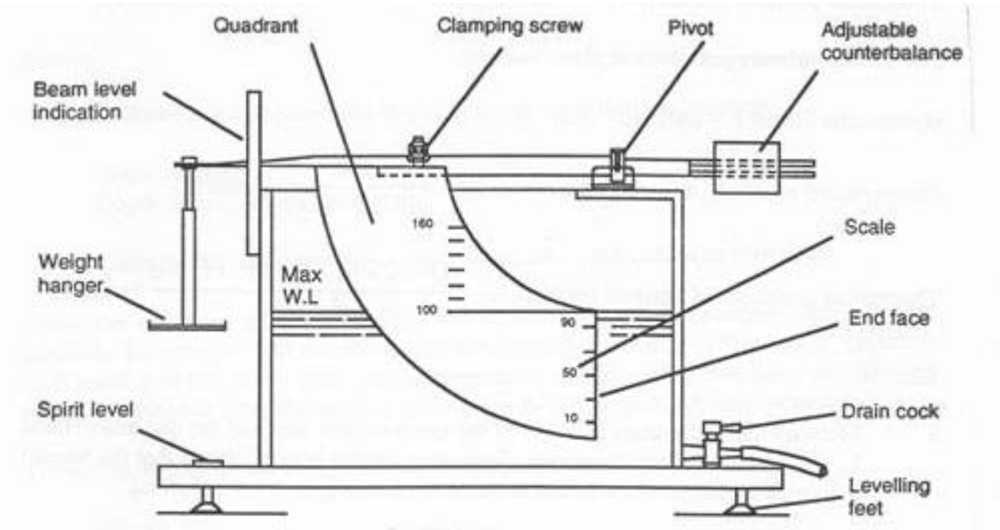


Figure 2.5:Center of pressure apparatus

Procedure:

1. Level the tank, by checking the “bubble level”.
2. Measure and take note of the designed dimensions by a, L, d and b.
3. Close the drain cock at the bottom of the tank. Move the counterbalance until the flat surface will be perpendicular to the base of the tank (base that we levelled previously). This step is very important in order to get good measurements.
4. Place a calibrated weight on the weight hanger and add water slowly until the Beam level is horizontal.
5. The fine adjustment of this level can be managed by refilling and draining slowly through its cap.
   Take note of the water level, indicated in the quadrant, and of the value of the weight located on the weight hanger.
6. Repeat the previous operation several times, increasing steadily the weight of the tray.

LAB SHEET (Center of Pressure on a Plane surface)

Calculations and Results:

-Height of the rectangular surface, d = 100 mm

-Width of the rectangular surface, b = 70 mm

-Distance between the balance pan and the pivot, L = 285 mm

-Distance between the top of the rectangular surface and the pivot level, a = 88 mm

NOTE: Those ranges of mass could be changed based on the experiment conditions

A mass on the balance pan m (gm)	Depth of water y (mm)	Immersion Case
30		Partial
50		
60		
70		
80		
90		
100		
140		
170		
200		
230		Full
260		
310		
340		
370		
390		
410		
430		
450		
460		

Partial Immersion:

m (kg)	Moment of weight= m *g* L	Depth of water y (m)	Moment of force = $\rho_w * g * \frac{y^2}{2} * b * (a + d - 1/3 * y)$	Error= Absolute difference col(2)-col(4)
0.03				
0.05				
0.06				
0.07				
0.08				
0.09				
0.1				
0.14				
0.17				
0.2				

Full Immersion:

m (kg)	Moment of weight= M*g * L	Depth of water y (m)	Moment of force= $\rho_w * g * \left(y - \frac{d}{2}\right) * b * d\ (a + d/2 + \frac{d^2}{12*(y-\frac{d}{2})}$	Error= Absolute difference col(2)-col(4)
0.23				
0.26				
0.31				
0.34				
0.37				
0.39				
0.41				
0.43				
0.45				
0.46				

Issues to be considered in your report:

- Plot values in col. (2) vs. values in col. (4) for each case.

- Compare the plotted curves vs. the theoretical line at 45° slope in each case.

-What are the potential sources of error in the experiment? How could they be overcome?
………
……………………………………………………………………….

- Does the derivation of the static force equation depend on whether the fluid is viscous or not? Explain.
………
……………………………………………………………………………………

- By examining equation (6):

a) Which is deeper the center of pressure or the center of area?
………
……………………………………………………………………………………....

b) What is the effect of water depth on the distance between center of pressure and center of area?..
....
....

- If there is an error in leveling the apparatus and the water surface was inclined by x° from the horizontal. How would this affect your results?
………
………
……………………………………………………………...

- Even there are surfaces other than the toroid rectangular surface affected by the hydrostatic forces, why aren't they taken into consideration in your calculations?
………
………
……………………………………………….

(3) Impact of a Jet

Objective:

This experiment enables to measure the force (m*g) developed by a jet of water deflected on a fixed impact object by comparing it to the force predicted by the momentum theory.

Theory:

Consider a vane symmetrical about the z-axis as shown in Fig. (3-1). A jet of water flowing at the mass flow rate of m° (Kg/s) along the positive z-axis with a velocity $u_\circ$ (m/s) strikes the vane and deflected along its surface through an angle β, so that the fluid leaves the vane with velocity u_1 (m/s) inclined at an angle β from z-axis.

Applying Newton's second law in the direction of the incident jet (z direction):

Force= Mass * Acceleration

-F-W-w = Mass flow rate * Δ velocity

-F-W-w = m° * (u_1 cos β - $u_\circ$)

-F-W-w= ρ * Q * (u_1 cos β - $u_\circ$)….(1)

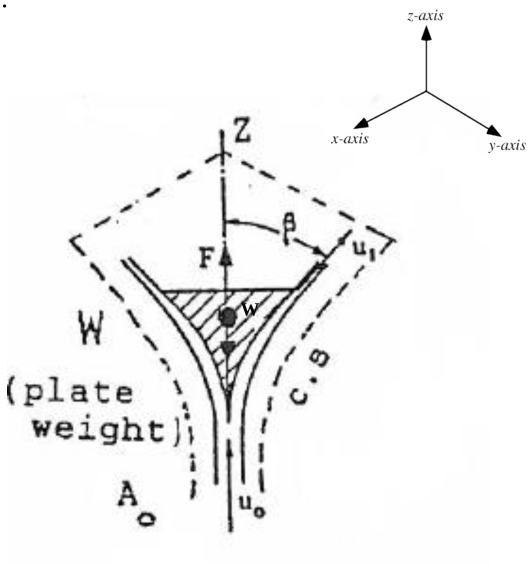


Figure3.1

-Where:

W = weight of water in the control volume.

w = plate weight.

F = reaction force in z-axis (added weights).

To find u_1, apply Bernoulli's Equation between both sections:

$$\frac{u\circ^2}{2g} + \frac{p\circ}{\rho g} + z\circ = \frac{u1^2}{2g} + \frac{p1}{\rho g} + z1$$

$p_\circ = p_1 = p_{atm} = 0$

Therefore,

$$\frac{u_\circ^2}{2g} + (z_\circ - z1) = \frac{u1^2}{2g}$$

$$\mathbf{u_1} = \sqrt{u_o^2 - 2 * g * \Delta z}$$

For very small Δz, the above equation yields $u_1 = u_\circ$

In addition, by neglecting W and w as the plate and water weight are so small compared to F, equation (1) becomes:

$-F = \rho * Q * u_\circ (\cos\beta - 1)$

Or:

$F = \rho * Q * u_\circ (1 - \cos\beta)$

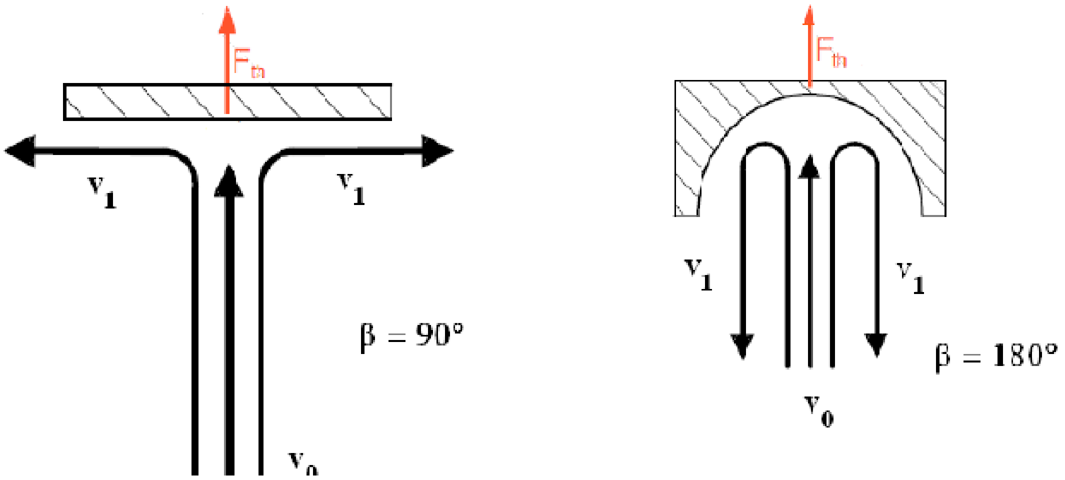


Figure3.2: Flat and Hemispherical objects

-For the case of **Flat object**, β = 90°, so cos β= 0:

$F = \rho * Q * u_\circ$

- For the case of ***Hemispherical object***, we may assume that β = 180°, so that cos β = -1:

$F = 2* \rho * Q * u_\circ$

-For the case of ***Conical object***, β = 45°, so cos β= 0.7071:

$F = 0.292893* \rho * Q * u_\circ$

<u>Apparatus:</u>

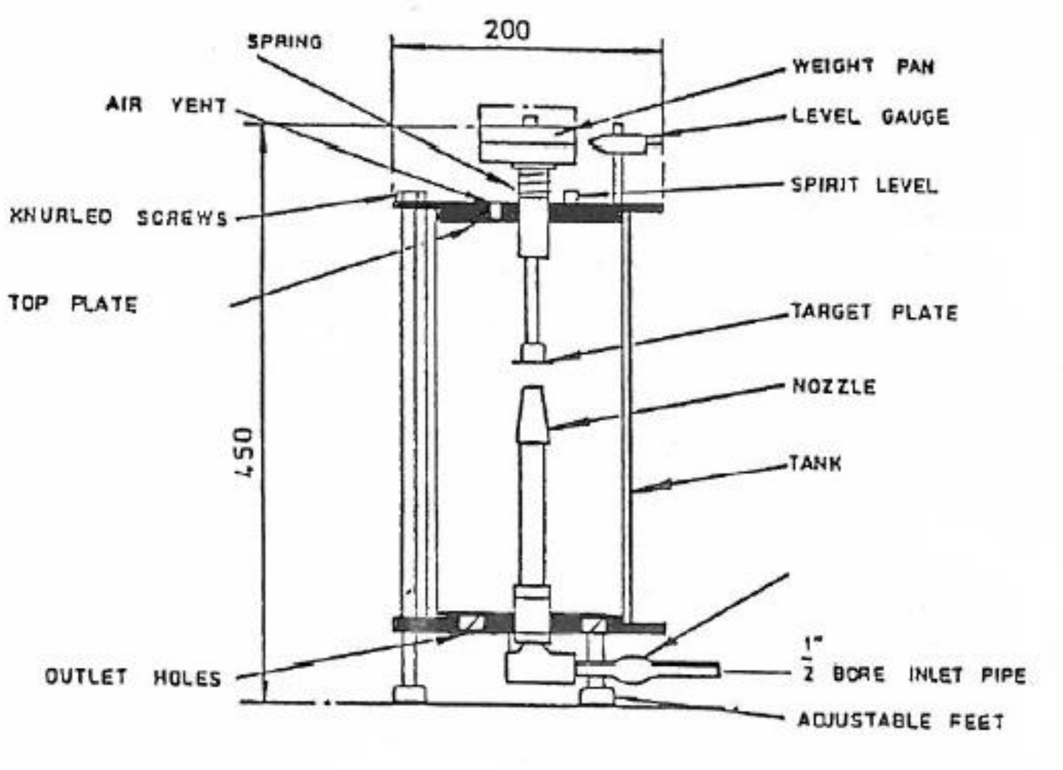


Figure3.3: Impact of a jet Apparatus

- The equipment is composed of a transparent cylinder inside which water is fed from a bottom pipe provided with an interchangeable nozzle. The jet produced by the nozzle strikes an object supported on a stem which extends through the cover.
- To counterbalance the force exerted by the water jet, weights are applied to the upper end of the stem.
- When there is jet of water, the force exerted by the last causes the stem to rise and this will be balanced by adding weights until the stem returns to its starting position.
- In this way it is possible to determine the force exerted by the jet of water on the object under test.
- 3 kinds of objects are available: a flat one, a conical one at 45° and a hemispherical one.

Procedure:

1. Remove the cover from the equipment by unscrewing the fixing Screws.

2. Screw the wished impact object to the support stem.

3. Set the cover and screw the fixing screws.

4. Adjust the pins so that the equipment is perfectly levelled.

5. Set the pointer besides the weight stem assembly to the red level (Balance position without jet).

6. A nominal mass is placed on the weight pan, then allow the water to flow (increase the flow rate step by step) by operating the control valve on the bench, and switch on the pump.

7. Adjust the flow rate until the weight pan is adjacent to the level gauge.

8. Take the readings as volume and time to find the flow rate.

9. Write down the mass on the weight pan.

10. Repeat steps 7-10 with additional masses on the weight pan.

11. Repeat the above steps by using the three different types of objects provided (flat one, a conical one at 45° and a hemispherical one).

LAB SHEET (Impact of a Jet)

Calculations and Results:

Nozzle Diameter: d= 8 mm

Nozzle Area: A= mm^2

Density of water: ρ= 1000 Kg/m^3

Flow Rate (Q) = V/t

Mass Flow Rate (m°) = ρ * Q

Velocity of water leaving the nozzle (v) = Q/A_{nozzle}

Force due to gravity = m * g

Force due to momentum differs for different plate.

***Flat Plate:**

Force due to momentum= $\rho * Q * u_{\circ}$

No.	Weight (g)	Water Volume (m^3)	Time (s)	Flow Rate (m^3/s)	Mass flow rate (Kg/s)	Velocity of water leaving the nozzle (m/s)	Force due to momentum (N)	Force due to gravity (N)
1	30							
2	40							
3	50							
4	60							
5	70							
6	80							
7	100							
8	120							

***Conical Plate:**

Force due to momentum= 0.292893* ρ * Q * $u_\circ$

No.	Weight (g)	Water Volume (m^3)	Time (s)	Flow Rate (m^3/s)	Mass flow rate (Kg/s)	Velocity of water leaving the nozzle (m/s)	Force due to momentum (N)	Force due to gravity (N)
1	30							
2	40							
3	50							
4	60							
5	70							
6	80							
7	100							
8	120							

***Hemispherical Plate:**

Force due to momentum= 2 * ρ * Q * $u_\circ$

No.	Weight (g)	Water Volume (m^3)	Time (s)	Flow Rate (m^3/s)	Mass flow rate (Kg/s)	Velocity of water leaving the nozzle (m/s)	Force due to momentum (N)	Force due to gravity (N)
1	30							
2	40							
3	50							
4	60							
5	70							
6	80							
7	100							
8	120							

Issues to be considered in your report:

- Draw the curves which show the relation between the gravitational force vs the momentum force for each plate.
- Compare these curves with a theoretical one which should pass through the origin with a 45° slope.

- Calculate the actual jet velocity when it hits the hemispherical cup taking into account the effect of gravity. (height between the nozzle and the water inlet to the cup is 20 mm)
……
……
……………………………………..............................

- If the experiment is carried out carefully by changing rhe flow rate very slowly down to zero, will the gravitational force vs momentum force curve pass through the origin? Explain your answer……
……
……………………………………………………….........

- What is the slope of the experimental gravitational force (mg) vs momentum force curve? What is the theoretical slope for each plate? Give expected reasons for the difference between both curves……
……
…………………………………………………………....

(4) Reynolds Number

Objective:

- To observe the laminar, transition and turbulent regimes and associate them with their corresponding Reynolds Number.

- To observe the velocity profile.

Theory:

I. Observing Reynolds Number

Reynolds number (Re) is a dimensionless quantity that is used to help predict similar flow patterns in different fluid flow situations. The Reynolds number is named after Osborne Reynolds, who popularized its use in 1883.

Hence, the nature of a given flow of incompressible fluid is characterized by its Reynolds's number. Reynolds's number is defined as a ratio of inertial forces (produce acceleration) to viscous forces (produce friction) or by mathematical expression:

$$\boldsymbol{Re} = \frac{inertia\ forces}{viscous\ forces} = \frac{\rho\ \mathrm{v}\ \mathrm{D}}{\mu} = \frac{\mathrm{v}\ \mathrm{D}}{\nu}$$

-Where:
v = Flow velocity (m/sec)
D= Characteristic diameter (m)
μ= **Dynamic** viscosity, also called **Absolute** viscosity (Pa. s)
ν = Kinematic viscosity (m^2/sec)
ρ=fluid density(Kg/m^3)

Consequently, and as a result of Reynolds's number, flow can be visualized as:

1. Laminar flow (Re ≤2000): fluid moves in a layer, or laminar, one layer gliding smoothly over an adjacent layer with only molecular interchange of momentum. Any tendencies toward erratic motion are damped out by viscous shear forces that resist relative motion of the adjacent fluid layers. For this condition friction losses are directly proportional to mean flow velocity.
It can be considered that the movement of the fluid is in layers and they do not mix. Under these conditions, the trajectories of the coloring particles can be easily identified as a line.

2. Turbulent flow (*Re* ≥4000): fluid here shows erratic motion where momentum interchanges are predominant. These interchanges reduce viscous effects appreciably and appear turbulent in a fine- scale for small *Re* number (eddies) or large scale for big *Re* number (huge vortices and swirls). For the condition friction losses is proportional to velocity to the power 1.7~ 2.

3. Transition flow (2000 < *Re* <4000): fluid is in situation of change from smoothly viscous motion to erratic turbulent motion. Particles are in a position of bearing both molecular and momentum motion which dominates more characterizes the condition.

Under these conditions, the coloring matter spreads in the water and the trajectory of its particles cannot be observed.

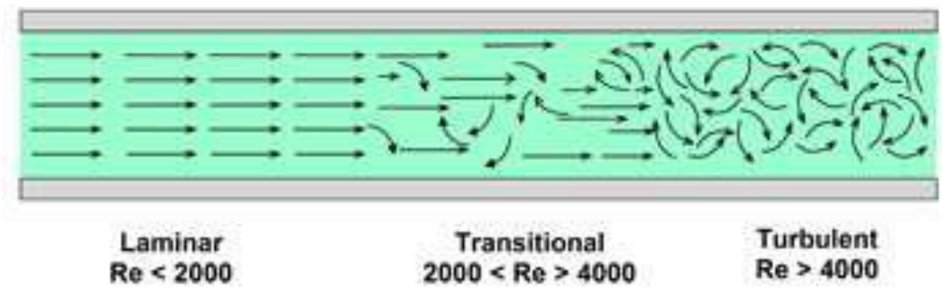


Figure 1: Reynolds numbers reflect how turbulent or laminar flow is in a flow stream.

II. Observing Velocity Profile

Parabolic velocity profile is the property that defines a fluid is its behavior against a shear force (a force that is tangential to its surface). A solid is distorted in the direction of the force, but a fluid acquires a certain velocity in such direction. However, the whole fluid does not gain the same velocity due to the friction among its different layers.

In the case of a tube, a difference of pressure has been applied to the fluid so that it moves. Friction with walls makes the velocity in the fluid which is touching them null. Velocity increases as the fluid is closer to the center of the tube. It generates the so-called parabolic velocity profile (or Poiseuille profile), with a maximum in the center and a null value in the walls.

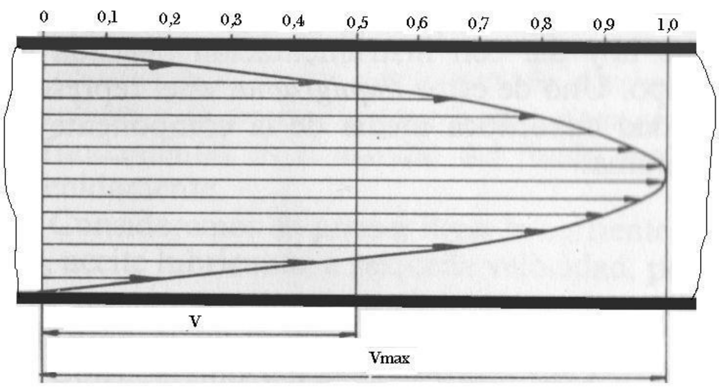


Figure 2: Parabolic velocity profile.

Apparatus and Materials:

- Hydraulic Bench.
- Osborne-Reynolds Demonstration.
- Coloring matter.

1. Tank for including ink
2. Coloring 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

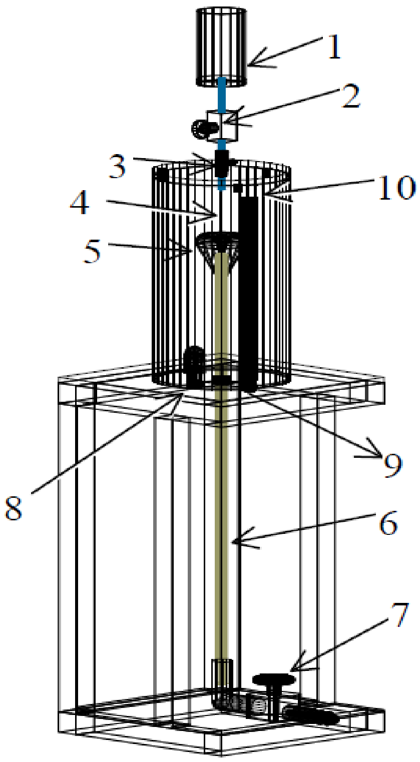


Figure 3 :Reynolds number apparatus

Procedure:

1- Fill the tank (1) with approximately 100 ml of water and add 15 ml of Coloring matter.

2- The feed pipe of Reynolds Apparatus is connected (8) to Hydraulic Bench. Place the discharge and drainage holes in the bench's spillway.

3- Put the injector down (4), by means of the screw (3), until placing it on the inlet nozzle (5) to the flow visualization tube (6).

4- Close the flow control valve (7).

5- Start the pump and fill the tank slowly until reaching the overflow level (10); afterwards close the control valve of the Hydraulic Bench or hydraulic group completely to avoid the return of the water, and stop the pump.

6- Open and close several times the flow control valve (7) to purge the visualization tube.

7- Wait until the liquid in the apparatus is steady, at least ten minutes, before going on with the experiment.

8- Start the pump and open the control valve of the bench or of the group carefully until the water comes out for the overflow.

9- Open the control valve partially (7) and when a constant level is achieved inside the cylinder (that exceeds the nozzle and the injector), open the coloring matter injection valve little by little (2) until getting a slow current with the coloring matter.

NOTE: The ink must go out very slowly, dragged by the water current.

10- Vary the flow with the control valve (7), until you are able to visualize along the tube the parallel line drawn by the ink inside the flow visualization tube (laminar regime).

11- By increasing the flow, opening the control valve progressively (7) and opening the flow control valve of the Bench at same time to compensate the flow drop due to the flow control valve (7), you can observe alterations in the ink.

It will begin to oscillate (transition regime), until finally the ink is dispersed completely in the water (turbulence regime).

12- Measure and write down the flow of each regime.

13- Measure the water temperature.

LAB SHEET (Reynolds Number)

Calculations and Results:

Measured Temperature =

Determine water kinematic viscosity suitable for the measured temperature.

Calculate the flow for each sampling (Q=V/t).

Knowing that the inner diameter of the glass tube is 10 mm and knowing the flow which flows through it, obtain the fluid velocity value (v=Q/A).

Calculate the Reynolds number for each flow.

Fill in the following table:

Trial.no	Volume (m^3)	Time(s)	Flow (m^3/s)	Velocity (m/s)	Reynolds Number	Type of flow
1						
2						
3						
4						
5						
6						

Issues to be considered in your report:

Make a diagram of the shape of the velocity profile inside the tube.

-What are the potential sources of error in the experiment? How could they be overcome?..

....

-How does the Reynolds number change with the flow increase?**..**

...

-Do these results have coherence with those obtained by Osborne Reynolds?**..**

...

-Which of the three regimes is the most adequate one if we want to obtain a fluid as homogeneous possible?...

-Why do we obtain the parabolic shape in the velocity profile?...

(5) Bernoulli's Equation

Objective:

Determination of the cross sectional area at each section in the Venturi's tube.

Theory:

Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.

Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy, potential energy and internal energy remains constant.

Total Head or Energy Head (H) can be calculated as:

$$H = z + \frac{p}{\rho g} + \frac{v^2}{2g} = h + \frac{v^2}{2g},$$ ---------Where:

H = Total Head or Energy Head (m); the height of the fluid above the point you are measuring.

z = is the elevation of the point above a certain datum

p = the pressure at the chosen point

ρ = the density of the fluid

g = the gravitational acceleration

v = the fluid flow velocity at a point on a streamline

h = z + P/ ρ ∗ g is the piezometric head or hydraulic head

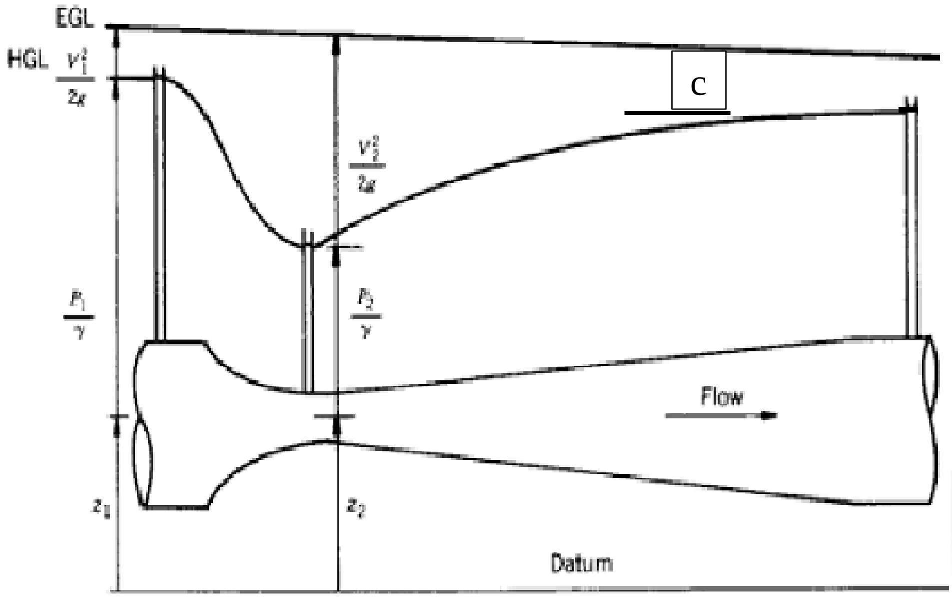


Figure 1: Venturi Tube

Considering the v_1^2 flow in two different sections of a pipe, and applying the law of conservation of the energy, Bernoulli´s equation may be written as

$$\frac{v1^2}{2g} + \frac{p1}{\rho g} + z1 = \frac{v2^2}{2g} + \frac{p2}{\rho g} + z2$$

But Z_1=Z_2, then:

$$\frac{v1^2}{2g} + \frac{p1}{\rho g} = \frac{v2^2}{2g} + \frac{p2}{\rho g}$$

Also, apply Bernoulli's equation between sections 2 and C :

$$\frac{v2^2}{2g} + \frac{p2}{\rho g} + z2 = \frac{vc^2}{2g} + \frac{pc}{\rho g} + (z2 + H)$$

But Pc = P_{atm} = 0 , $z_2 = z_c = 0$ and $V_c = 0$, then:

$$\frac{v2^2}{2g} + \frac{p2}{\rho g} = H$$

-Where,

= Piezometric height: It is the height of one water column associated with the pressure of the gravitation $\frac{p2}{\rho g}$ field. $\frac{v2^2}{2g}$= Kinetic height.

Apparatus:

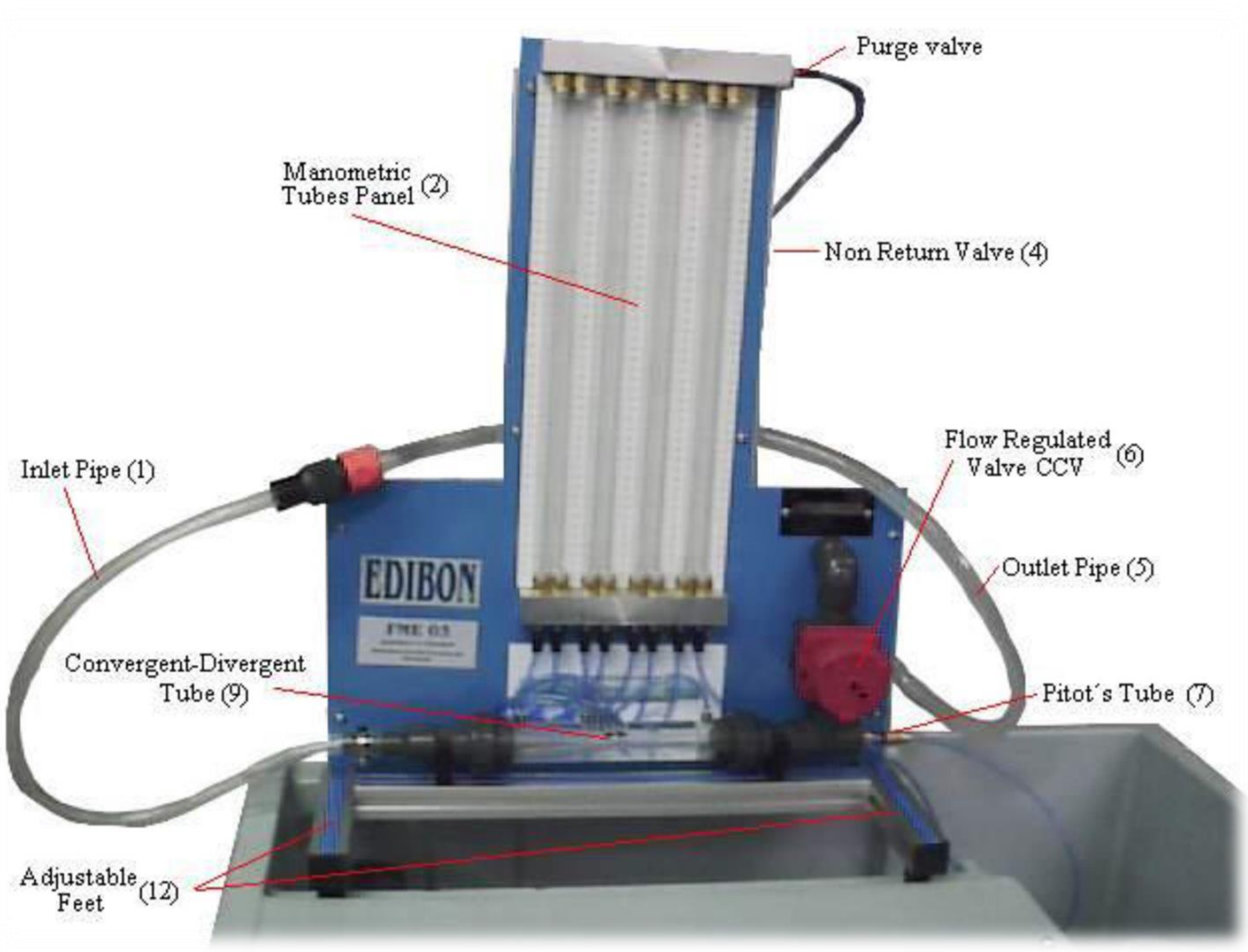


Figure 2:Bernolli Apparatus

The Bernoulli´s Apparatus is mainly composed of seven pressure valves that are able to measure, simultaneously, the static pressure values ($\frac{p2}{\rho g}$)corresponding to each point of seven different sections.

All the pressure valves are connected to a manometer; rank of each manometer: 0-500 mm of water.

The ends of the conduit are removable, enabling, consequently, to place it in either convergent or divergent form with respect to the stream direction.

Also, there is a probe (Pitot´s tube) travelling along the conduct for measuring the Total Head or Energy Head (H).

For the practice, the equipment needs to be assembled on base board of the bench and has adjusted legs to level the equipment.

Procedure:

I. To fill the manometric tubes:

1. Close the flow control valve of the Hydraulic Bench (CV), and also close the flow control valve of the equipment (CCV).

2. Switch on the water pump and open completely the CCV valve. Open slowly the CV valve until the maximum flow is obtained. When all the manometric tubes are completely filled of water and there is not any air bubble, close the CCV and then the CV . It is important to maintain this order of closing, because if do not, the manometric tubes will be empty of water.

3. Open the purge valve then start compressing the fluid until it gets hard to continue then close the purge valve.

4. Open slowly the CCV valve. You can observe how the manometric tubes begin to fill itself of air.

5. When all the tubes have obtained the desired height (70 or 80 mm), close the CCV valve.

6. After 5 minutes, all tubes have the same water level.

II. To measure the cross-sectional area of the Venturi's Tube:

1- Fill all the manometric tubes as indicated in the previous section.

2- Open the flow valve of the hydrostatic bench and the regulation valve of the equipment.

3- Fix the water flow, and write down its value.

4- Place the Pitot’s tube in the first pressure taking of a minimum section. Wait until the height of the Pitot’s manometer becomes stable. This process can last some minutes.

5- When the heights of both tubes are stable, determine the difference of height between the two manometric tubes; static pressure “hi” and total pressure “H” (Pitot’s tube).

6- This difference corresponds to the kinetic pressure given by “$V^2/2g$”.

7- Determine the area by the following equation: A=Q/V, where Q is the water flow and V is the water velocity $V=\sqrt{2*g*(H-hi)}$.

8-Repeat all the previous steps for different water flows.

9-For each water flow, the section must be more or less the same. Make the average of the sections obtained with different water flows.

Do these steps for both Convergent and divergent forms.

LAB SHEET (Bernoulli's Equation)

Calculations and Results:

$Q=\frac{volume}{time}$

$V=\sqrt{2*g*(H-hi)}$

$A=\frac{Q}{V}$

Case I : Converging Flow

To be repeated for two different discharges

Total Head measured by probe (H_1) = mm

Average flow rate (Q_1) = mm

i	hi mm	H_1 - hi (mm)	V (mm/s)	$(Ai)_1$ mm^2
1				
2				
3				
4				
5				
6				

Total Head measured by probe (H_2) = mm

Average flow rate (Q_2) = mm

i	hi mm	H_2 - hi (mm)	V (mm/s)	$(Ai)_2$ mm^2	Aavg $((Ai)_1+(Ai)_2)/2$
1					
2					
3					
4					
5					
6					

Case II: Diverging Flow

To be repeated for two different discharges

Total Head measured by probe (H_1) = mm

Average flow rate (Q_1) = mm

i	hi mm	H_1 - hi (mm)	V (mm/s)	Ai mm^2
1				
2				
3				
4				
5				
6				

Total Head measured by probe (H_2) = mm

Average flow rate (Q_2) = mm

i	hi mm	H_2 - hi (mm)	V (mm/s)	Ai mm^2	Aavg $((Ai)_1+(Ai)_2)/2$
1					
2					
3					
4					
5					
6					

Issues to be considered in your report:

- Compare the cross sectional area obtained in each section, in both converging and diverging flow.

-What are the potential sources of error in the experiment? How could they be overcome?..

....

- What is the relation between the Kinetic head and piezoemetric head? Explain this relation………

……………………………………………………………………………………

-What is the relation between the flow (Q) and the total head (H)? Explain this relation………

…………………………………………………………………………………….

(6) Head Losses

Objective:

The goal of this experiment is to determine the local (minor) and linear (major) head losses to investigate how they are influenced by the flow speed.

Theory:

Viscous flow in a pipe can be characterized based on the Reynolds number, Re which is the ratio of flow inertia to the viscous effects.

$$\boldsymbol{Re} = \frac{inertia\ forces}{viscous\ forces} = \frac{\rho\ \mathrm{v}\ D}{\mu} = \frac{\mathrm{v}\ D}{\nu}$$

-Where:
v = Flow velocity (m/sec)
D= Characteristic diameter (m)
μ= Dynamic viscosity, also called Absolute viscosity (Pa.s)
ν = Kinematic viscosity (m^2/sec)

In a steady incompressible pipe flow, the viscous effects as well as other irreversibility's can be incorporated into the Bernoulli equation in terms of a head loss. In general, losses in a straight pipe due to its friction (surface roughness and length) and viscous action are referred to major losses, ($\mathbf{H_{major}}$), and losses associated with other effects (i.e valves, fittings, junctions, bends, throttles, sudden expansion and contraction, etc.) are referred to minor losses, ($\mathbf{H_{minor}}$). When viscous effects are considered, extended Bernoulli equation is expressed by:

$$\frac{v^2}{2g} + \frac{p}{\rho g} + z + H_{major} + H_{minor} = H$$

The magnitude of both major and minor losses is proportional to the velocity head ($v^2/2g$), as noted from the equations below.

A) Losses due to friction:

Friction losses in pipes are estimated by Darcy-Weisbach formula as:

$$H_{major=}f\ \frac{L}{D}\frac{v^2}{2*g}$$

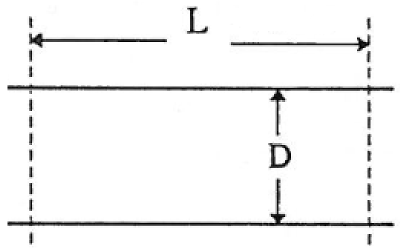


Figure 1:straight losses

Where:

f = is the friction factor

l = is the length of the pipe

D = pipe diameter

v = fluid's velocity

g = is the gravitational acceleration.

Friction coefficient "f" is a function of Reynolds number and internal surface roughness of the pipe.

In the laminar flow (Re<2000):

$$f=\frac{64}{Re}$$

While for large values of Reynolds number; turbulent flow, the friction coefficient can be approximated by the Blasius equation ,which is only applicable to flow in smooth pipes as follows:

$$f=\frac{0.316}{Re^{0.25}}$$

B) Losses due to sudden expansion:

For the pipe shown in Fig. (2), head losses H_l is calculated by the expression:

$$H_{l=}\frac{(v_1 - v_2)^2}{2 * g}$$

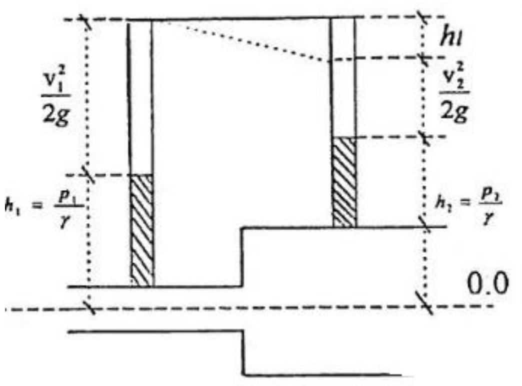


Figure 2:Expansion Losses

C) Losses due to sudden contraction:

For the pipe shown aside, Fig. (3), head losses H_l is given by the expression:

$$H_{l=}\,Kc * \frac{{v_2}^2}{2 * g}$$

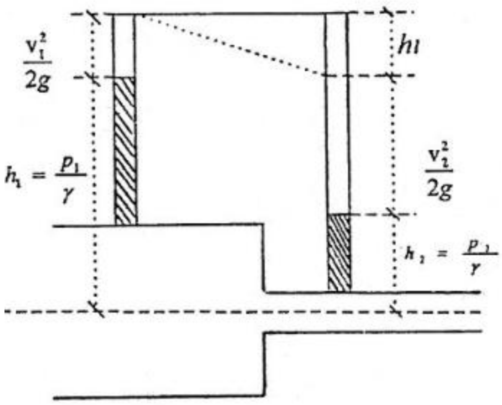


Figure 3:Contraction Losses

Where Kc is a dimensionless coefficient, which depends upon the area ratio as shown in the table below:

A_2/A_1	0	0.1	0.2	0.3	0.4	0.5	0.8	1.0
Kc	0.5	0.46	0.41	0.36	0.30	0.18	0.06	0

D) Losses due to valves

The head losses due to a valve is given by the expression:

$$H_{l=}\ Kv * \frac{{v_2}^2}{2 * g}$$

Where the value of K depends on the type of valve and the degree of opening. Table below gives typical values of losses coefficient for gate, globe and Ball valves.

Globe Valve, fully open	10.0
Gate Valve, fully open	0.2
Gate Valve, half open	5.6
Ball Check Valve	4.0

Ball Valves: Inside a ball valve, a sphere usually made of brass, chrome-plated brass, or stainless steel has been drilled through from one end to the other, as shown in Fig.(4). You can control the flow by moving the lever between 0° and 90°.

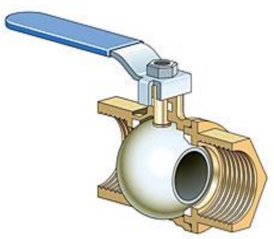


Figure (4): Ball Valve

Gate Valves*:* A gate valve is operated with a wheel that moves a gate up and down. When the gate is in the lowest position, it blocks the flow of water; when it's in the highest position, water can flow freely as illustrated in Fig. (5).

Figure (5): Gate Valve

Globe Valves**:** Unlike ball valves and gate valves, globe valves are designed for limiting the flow of water. They are operated with a wheel and a stem like gate valves, but the stem is attached to a stopper that seals shut a baffle—essentially two half-walls that force the water to flow in a Z-pattern.

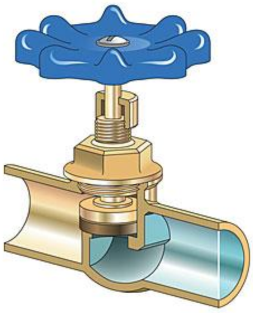


Figure (6): Globe Valve

E) Losses due to bends:

The head loss due to bend is given by the expression:

$$H_{l=}\ K_B * \frac{v_2{}^2}{2 * g}$$

Where K_B is a dimensionless coefficient which depends upon the bend radius per pipe radius ratio and the angle of the bend. Table below gives typical values of losses coefficient for standard bends.

Return Bend	2.2
Standard Tee	1.8
Standard Elbow	0.9
45° Elbow	0.42
90° Elbow	0.75

Apparatus

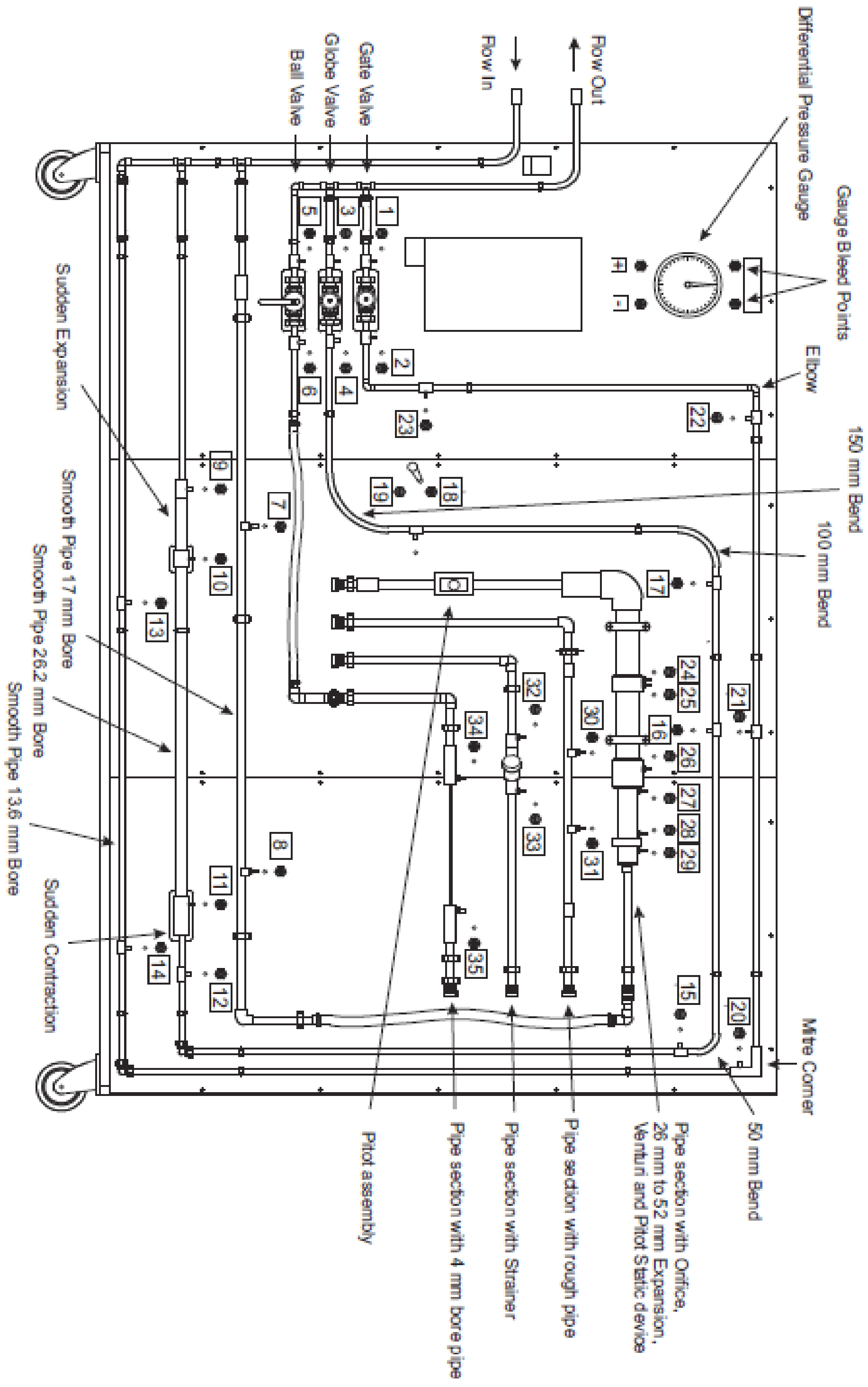


Figure (7): Layout of the Apparatus

Table 1 lists all the pipes and fittings on the apparatus, as well as their respective tapping numbers.

Item	Details	Tapping Numbers	Distances Between Tappings
Gate Valve		1, 2	-
Globe Valve		3, 4	-
Ball Valve		5, 6	-
Smooth Pipe	17 mm Diameter Bore	7, 8	912 mm
Sudden Enlargement	13.6 mm to 26.2 mm	9, 10	-
Sudden Contraction	26.2 mm to 13.6 mm	11, 12	-
Smooth Pipe	26.2 mm Diameter Bore	10, 11	912 mm
Smooth Pipe	13.6 mm Diameter Bore	13, 14	912 mm
Radius Bend	50 mm	15, 16	920 mm
Radius Bend	100 mm	17, 18	864 mm
Radius Bend	150 mm	19, 4	652 mm
Mitre Corner		20, 21	-
Elbow	13.6 mm Radius	22, 23	-
Orifice	20 mm Diameter	24, 25	-
Expansion	26 mm to 52 mm	26, 27	-
Venturi	d_1 = 26 mm Diameter d_2 = 16 mm Diameter	28, 29	-
Rough Pipe	17 mm Diameter Bore 14 mm Effective Diameter	30, 31	200 mm
Strainer	Includes Two Different Filters	32, 33	-
Smooth Pipe	4 mm Diameter Bore	34, 35	350 mm
Inlet Pipe	Coloured White	-	-
Outlet Pipe	Coloured Black	-	-

The apparatus has three colour coded circuits each fitted with a different control valve and a selection of pipes and pipe fittings.
Numbered pressure tappings are fitted at all the important points, for measurement of the pressure change along each pipe section or pipe component. Each pressure tapping includes a special self sealing connector.

To measure the pressure change across each pipe section or components, a free standing 3 way Piezometer unit is supplied. To measure the higher differential pressure across the valves and strainer, a differential pressure gauge is included. Suitable lengths of connecting pipes are supplied with the apparatus.
For very low flow rate measurement a 1000 mL measuring cylinder (supplied) allows a more accurate volume/time method when
used in conjunction with the hydraulic bench supply.

The pipe sections and pipe components include:
• A roughened pipe and smooth pipes of different internal diameters
• A selection of bends, an elbow and a mitre corner
• Three different types of valve
• Orifice and Venturi meters
• An in-line Strainer supplied with two different filters
•Sudden expansion and sudden contractions

Procedure:

Losses in Straight Pipes Experiments:

(1) Close the Globe valve and the Ball valve (light blue and grey circuits). Open the Gate valve (dark blue circuit) half of a turn.
(2) Turn on the cold water supply and wait for any trapped air to leave the circuit, then close the Gate valve
(3) Connect one set of piezometer tubes to tappings 13 (upstream) and 14 (downstream), if necessary,bleed the pipes.
(4) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale.
(5) Fully open the gate valve and wait for the flow to settle. Record the readings.
(6) Use the Gate valve to reduce the flow rate in five suitable steps to give a good spread of results.
(7) Use the measuring cylinder (supplied) and a stopwatch to measure the flow rate , as the flow rate is very low.

Losses in Sudden Expansion and Contraction Experiments:

(1) Close the Gate valve and the Ball valve (dark blue and grey circuits). Open the Globe valve (light blue circuit) half of a turn.
(2) Turn on the cold water supply and wait for any trapped air to leave the circuit, then close the Globe valve.
(3) Connect one of the sets of piezometer tubes to the tappings at each side of the sudden expansion (tapping numbers: 9, 10) and a second set of piezometer tubes to the tappings at each side of the sudden contraction (tapping numbers: 11, 12). If necessary,bleed the pipes.
(4) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks.
(5) Fully open the Globe valve and wait for the flow to settle. Record the readings.
(6) Use the Globe valve to reduce the flow rate in five suitable steps to give a good spread of results.

Losses in Valves:

(1) Fully open the Gate valve and close the other two valves.
(2) Turn on the cold water supply and wait for any trapped air to leave the circuit.
(3) Connect one of the sets of piezometer tubes to the tappings (Gate Valve: 1, 2 & Globe Valve: 3,4)) at each side of the valve. If necessary, bleed the pipes.
(4) Use the hand pump if necessary to adjust the pressure in the Piezometer tubes until the levels are halfway up the scale. The level in each of the Piezometer tubes should be the same, if not then check for air bubbles or leaks.
(5) Leave the valve fully open and reduce the water supply flow rate in five suitable steps to give a good spread of results. Record all the readings.
(6) Repeat for the gate valve.

LAB SHEET (Head Losses)

Calculations and Results:

Losses in Straight Pipes Experiments:

Pipe Length, L = 0.912 m
Pipe Diameter, d = .0136 m
Pipe Internal Area, A = m^2

① Head Loss, h_l, (m) [h3-h4]	② Discharge, Q, (m^3/sec)	③ Flow velocity, v *(m/sec)*	④ R_e $\frac{vd}{\upsilon}$	⑤ Experimental f $\left[\frac{2gd}{Lv^2}h_l\right]$	♣⑥ Blasius's f $\left[\frac{0.316}{R_e^{\frac{1}{4}}}\right]$	⑦ [Log h_l]	⑧ [Log Q]

♣ *Note*: Check from Moody - diagram

- Plot. Log h_l vs. Log Q and fined the slope $\frac{\Delta(\text{Log}\,h_l)}{\Delta(\text{Log}\,Q)}$
- Plot. f (cols. 5 & 6) vs. R_e (col. 4) and comment.

Calculations and Results:

Losses in Sudden Expansion Experiments(Tapping Numbers: 9, 10):

Diameter of smaller pipe, d_1 = .0136 m
Area of smaller pipe, A_1 = m^2
Diameter of larger pipe, d_2 = .0262 m
Area of larger pipe, A_2 = m^2

① Measured head rise, (m) $[h_8 - h_7]$	② Velocity v_1 (m/sec) $\frac{Q}{A_1}$	③ Velocity v_2 (m/sec) $\frac{Q}{A_2}$	④ Assuming $h_l = 0$ Calculation head rise (m) $\frac{v_1^2 - v_2^2}{2g}$	⑤ Assuming $h_l \neq 0$ Calculated head rise (m) $\frac{v_1^2 - v_2^2}{2g} - \frac{(v_1 - v_2)^2}{2g}$

- Plot measured head rise (col. 1) against calculated ones (cols. 4 & 5), and Compare with the theoretical one which is plotted at 45° slope.

Losses in Sudden Contraction Experiments (Tapping Numbers: 11, 12):

Diameter of smaller pipe, d_2	=	.0136 m
Area of smaller pipe, A_2	=	m^2
Diameter of larger pipe, d_1	=	.0262 m
Area of larger pipe, A_1	=	m^2
A_2/A_1	=	
K	=	

① Measured head rise, (m) $[h_9 - h_{10}]$	② Velocity v_1 (m/sec) $\frac{Q}{A_1}$	③ Velocity v_2 (m/sec) $\frac{Q}{A_2}$	④ Assuming $h_l = 0$ Calculation head fall (m) $\frac{v_2^2 - v_1^2}{2g}$	⑤ Assuming $h_l \neq 0$ Calculated head fall (m) $\frac{v_2^2 - v_1^2}{2g} + K\frac{v_2^2}{2g}$

- Plot measured head fall (col. 1) against calculated ones (cols. 4 & 5), and Compare with the theoretical one which is plotted at 45° slope.

Losses in Valves

		Measured head Losses as H_2O, $h_{l\ H_2O}$ (m)	Pipe Diameter D (m)	Discharge Q (m^3/sec)	Velocity v (m/sec)	$K=\frac{2g}{v^2}h_{l\ H_2O}$ Valve Losses Coefficient, K
Globe Valve	1					
	2					
	3					
	4					
	5					
Gate Valve	1					
	2					
	3					
	4					
	5					

(7) Centrifugal Pump

<u>Objective:</u>

1. To study the basic characteristics of a centrifugal pump.

2. To study the performance of two pumps operating in parallel and in series.

<u>Theory:</u>

A hydraulic pump is a generator machine that is able to get energy to the fluid that circulates through its interior. This way, the fluid can overcome the geometric difference or the adverse gradient of pressures that could exist between two points of a hydraulic net.

Among all the hydraulic machines, pumps are the most versatile, because it is possible to adapt them to a great diversity of conditions of exploitation (powers, flows, elevation heights, liquids, materials, etc.).

I. Hydraulic Calculations:

Variables glossary:

* p: Relative pressure [P]
* H: Total head [m]
* z: Geometric elevation [m]
* Q: Flow [m^3/s])
* F: Force transmitted from motor stator to bedplate [N]
* τ: Mechanical torque [N.m]
* ω: Turning (angular) speed [rev/min]; [rad/s]
* N: Power [W]
* $\mathcal{E}$: Total efficiency of the pump
* p_s: Pressure at suction.
* p_d: Pressure at discharge (delivery).
* h: hydraulic.
* m: mechanical.
* □: Specific weight of the fluid (□ = □ * g)

where □ is the density of the fluid and g is the gravitational acceleration [N/m^3].

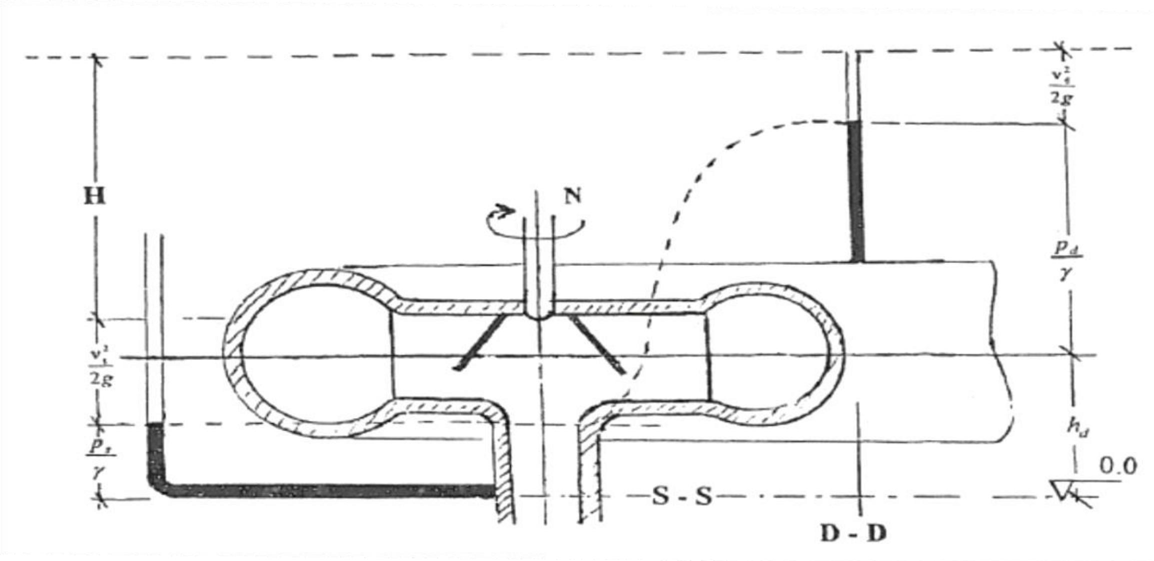


Figure (1):Section in the pump

By applying Bernoulli's equation between the delivery and suction sections:

$$\frac{vs^2}{2g} + \frac{ps}{\rho g} + H = \frac{vd^2}{2g} + \frac{pd}{\rho g} + h\mathrm{d}$$

-Where:
H : the head produced by the pump to the flow fluid
h_d: elevation difference

But:
Elevation difference is so small compared to pressure head difference.
For the same suction and delivery pipe diameters $v_s = v_d$ (same area and same flow).

Thus, the previous equation becomes:

$$Ht = \frac{pd - ps}{\rho g}$$

II. Power Calculations:

The value of the hydraulic power (output power) transmitted to the fluid by the pump can be obtained by the expression:

$$N_h = \gamma * Q * Ht$$

To know the mechanical power supplied by the motor (input power) the equation applied is:

$$N_m = \tau * \omega$$

III. Efficiency Calculations:

Efficiency is one of the most important parameters to study in a pump. Its value will greatly determine the economy of the exploitation.

The total efficiency of the pump is the efficiency of the machine as a whole, which includes the mechanical term and the hydraulic term:

$$\mathcal{E}=\frac{Nh}{Nm}$$

IV. Pumps in Parallel and series:

The efficiency of a pump varies with the discharge rate of the pump and the height over which the delivery is made. The optimum efficiency of a pump can be obtained only over a limited range of operation.

To install a pumping station that can be effectively operated over a large range of fluctuations in both discharge and pressure, it may be advantageous to install several identical pumps at the station.

When several pumps are connected in parallel in a pipeline, the discharge is increased but the pressure head remains the same as with a single pump. It should be noted that two identical pumps operating in parallel may not double the discharge in a pipeline since the total head loss in a pipeline is proportional to the second power of discharge. The additional resistance in the pipeline will cause a reduction in the total discharge. The figure below shows schematically the operation of two identical pumps in parallel. The joint discharge of the two pumps is always less than twice the discharge of a single pump.

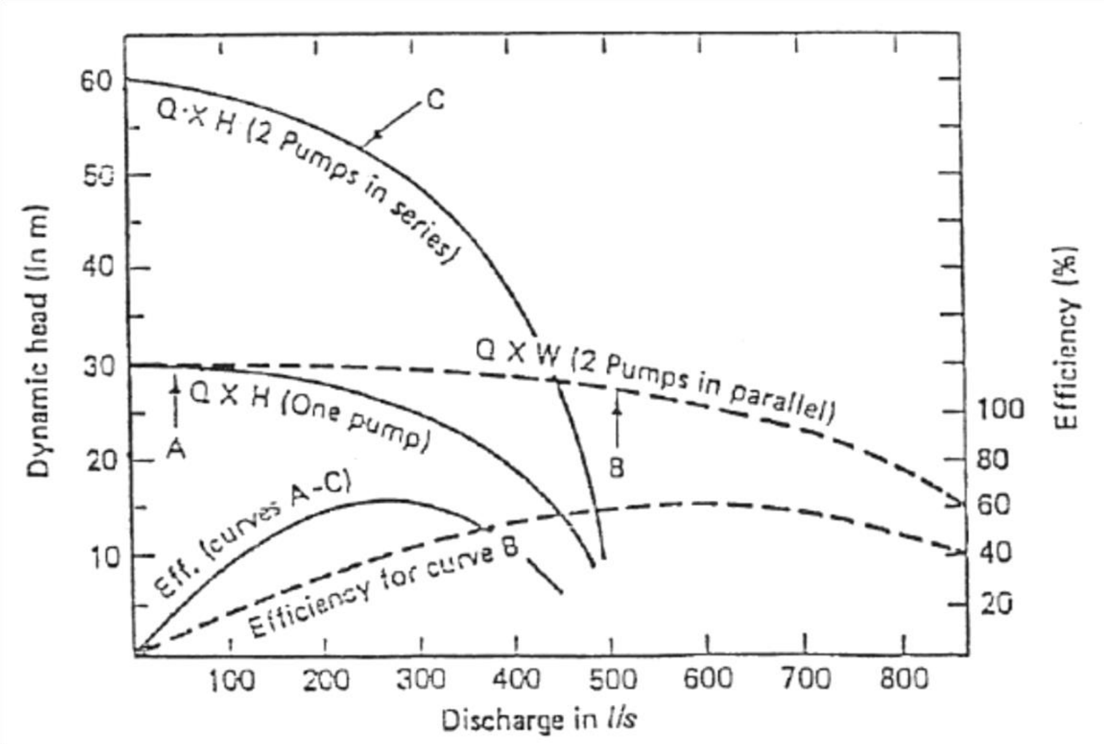


Figure (2): Typical performance curves of two pumps connected in parallel (B) and in series (C).

Pumps connected in series in a pipeline will increase the total output pressure, but the discharge will remain approximately the same as that of a single pump. A typical performance curve for two pumps connected in series is shown by curve C in Fig. (2).

The efficiency of two (or more) pumps operating in parallel or in series is almost the same as that of the single pump. The installation can be arranged with one separate motor for each pump or with one motor to operate two (or more) pumps. Multi-pump installations could be designed to perform either in -series or in- parallel operations with the same set of pumps.

Fig. (3) is a typical schematic of such an installation. For series operations, valve A is opened and valves B and C are closed; for parallel operations, valve A is closed and valves B and C are opened.

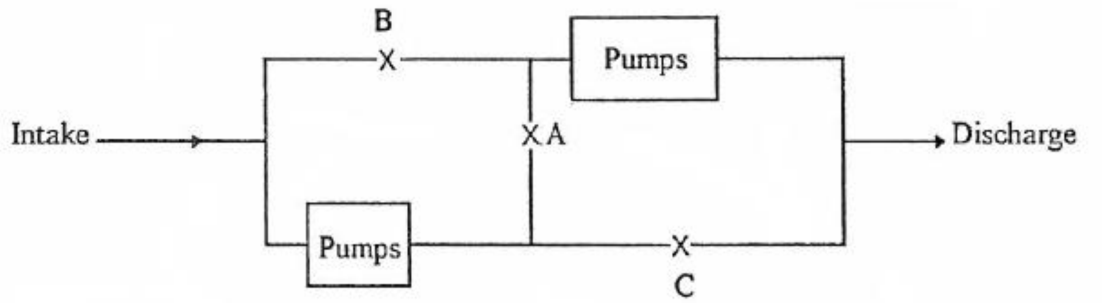


Figure (3) : Schematic installation for operation in series or in parallel

Apparatus:

The test equipment consists of two centrifugal pumps, an “interface” control panel, a deposit and circulation pipes with valves at the inlet and outlet of the pumps, three pressure sensors/meters, a rotameter, a load cell and a speed sensor/meter.

The centrifugal pumps supplied with the equipment can operate: alone,
coupled in series or in parallel.

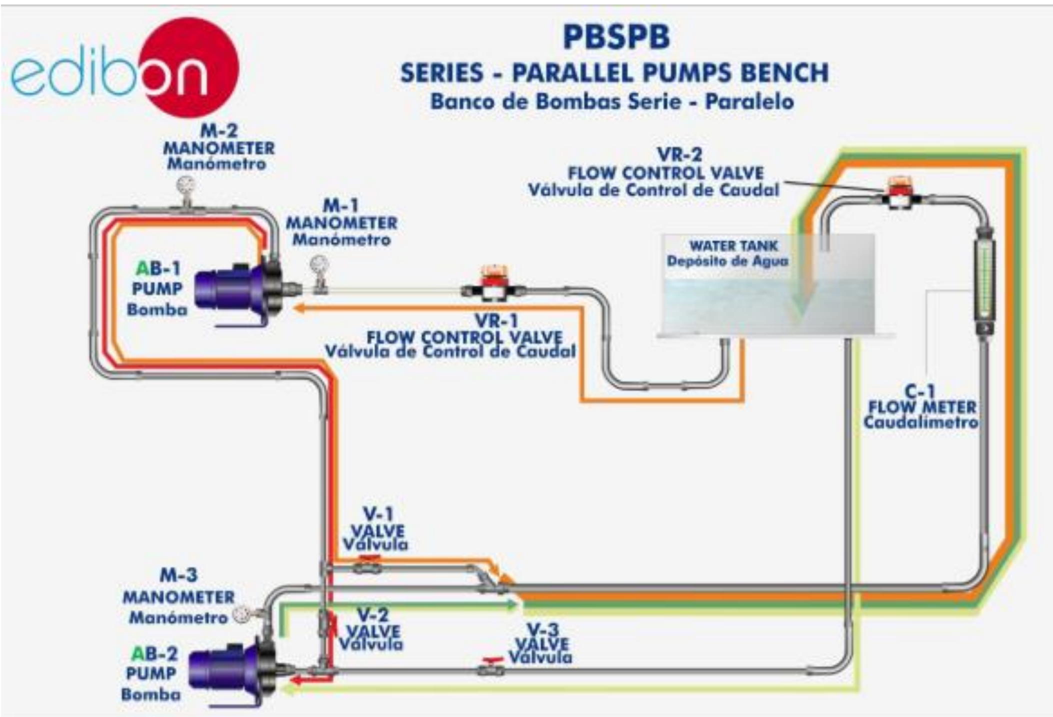


Figure (4): Hydraulic Diagram of the unit

The pumps are installed in a pipe system like the one shown in the diagram above, which is designed as a closed circuit to avoid the permanent waste of water during the operation.

By the appropriate positioning of the valves - See table (1)- it is possible to connect the pumps individually, in series or in parallel, depending on which test is going to be performed.

	PUMP B1	PUMP B2	SERIES Configuration	PARALLEL Configuration
VALVE VR-1	ADJUSTABLE	-	OPEN	OPEN
VALVE V1	OPEN	CLOSED	CLOSED	OPEN
VALVE V2	CLOSED	CLOSED	OPEN	CLOSED
VALVE V3	CLOSED	OPEN	CLOSED	OPEN
VALVE VR-2	ADJUSTABLE	ADJUSTABLE	ADJUSTABLE	ADJUSTABLE

Table (1): Scheme of the possible configurations of the unit according to the position of the valves

The reading of the measured magnitudes is carried out in the corresponding “PSBPC” software supplied with the unit. The user can control the turning speed of pump B1, as well as plot the characteristics of the pumps with the software.

Procedure:

I. Characteristics of a single pump

1. Boot the computer and run the PBSPC program.
2.Select the option “Characteristics of a pump” in the “select experiment” pull-down menu.
3.Turn on pump 1 through AB-1 and set the speed to 3000 r.p.m.
4.Open VR-2 slightly to set a moderate flow (Q < 20 l/min).
5.Save the data obtained for those conditions. To do that, press “AVERAGE” when data are stable. After 5-10 seconds, click “CAPTURE”.
6.When the “CAPTURE” button is pressed, the values will appear on the table of the central panel and they will be saved in the folder chosen when starting the software.
7.Set a new configuration closing VR-1 gradually, obtaining new values for SP-1.
8.Repeat these steps until several points for the set flow are obtained. Save the data obtained for each configuration, repeating the previous steps.

II. Pumps in Series

1. Boot the computer and run the PBSPC program.
2. Select the option “Series coupling of two pumps” in the “select experiment” pull-down menu.
3. The software will request the pump 2 characteristic data in the window, but its velocity must not be changed (because no data are obtained for this pump). This file can be created by the user or you can use the one provided with the software with the pump characteristics, called ONEPUMP.
4. When these values have been introduced, the software will request the location to save the data from the test in another window.
5. Switch on pump 1 through AB-1, set the speed to 3000 r.p.m. (thus, its speed is the same as for pump 2) and press the button to switch on pump 2, AB-2.
6. Save the data obtained for those conditions. To do that, press “AVERAGE” when data are stable. After 5-10 seconds, click on “CAPTURE”.
7. When the “CAPTURE” button is pressed, the values will appear on the table of the central panel and they will be saved in the folder chosen when starting the software.
8 Set a new configuration, closing VR-2 gradually until the flow range of the pump is complete and the flow is stopped. Save the data obtained for each configuration repeating the previous steps.

II. Pumps in Parallel

1. Boot the computer and run the PBSPC program.
2. Select the option “parallel coupling of two pumps” in the “select experiment” pull-down menu.
3. The software will request the pump 2 characteristic data in a window, but its velocity must not be (because no data are obtained for this pump). This file can be created by the user (loading the data obtained in the practical exercise 1, since its curve is supposed to be identical to that of pump 1 under the same working conditions) or you can use the one provided with the software with the pump characteristics, called ONEPUMP.
4. When these values have been introduced, the software will request the location to save the data from the test in another window.
5. Switch on pump 1 through AB-1, set the speed to 3000 r.p.m and press the button to switch on pump 2, AB-2.
6. Save the data obtained for those conditions. To do this, when data are stable, press the button “AVERAGE” and after 5- 10 seconds click on “CAPTURE”.
7. When the “CAPTURE” button is pressed, the values will appear on the table of the central panel and they will be saved in the folder chosen when starting the software.
8. Set a new configuration, closing VR-2 gradually until the flow range of the pump is complete and the flow is stopped. Save the data obtained for each configuration, repeating the previous steps.

LAB SHEET (Centrifugal Pumps)

Calculations and Results:

For each case; single pump, pumps in series and pumps in parallel:

1.Find the output and input power and efficiency for the first sample of each case . show your calculations.

2.Plot total head (H_t) vs. discharge (Q).

3.Plot Efficiency (τ) vs. discharge (Q).

4.find the maximum efficiency and at which case ?

Note: All curves should be on the same graph, but with different y-axis scale.

Issues to be considered in your report:

1. From your characteristics curve, is the discharge of combined pumps connected in parallel or series equals the sum of discharges for each pump? Comment on your results
……….

2. a- If you buy a pump and you find the head delivered under your required discharge is not attained , how would you solve this problem?...
b- If you buy a pump and you find the discharge delivered under your required head , how would you solve this problem?...

3. Locate your operating point; the point on the characteristic curve that corresponds to the maximum efficiency……………………………………………………………………………………………………….

4. From your graph, at the point of intersection of both characteristics curve (in series and in parallel) of pumps, what are the corresponding head and discharge? At that point what combinations do you select from power point of view and why?...
5. Comment on the efficiency of each pump, if the acceptable efficiency for industrial use is about 75%, is our obtained efficiency accepted?...

(8) *Water Hammer Apparatus*

Introduction

The Water Hammer Apparatus is one of many products in the Fluid Mechanics Range manufactured by TecQuipment Ltd.

The apparatus, illustrated in Figure 1, allows students to study the pressure waves that can arise when the flow of water in a pipe is arrested. It consists mainly of a large flat working surface (table top) mounted onto a large coil of copper pipe. The table top is large enough to place additional instrumentation on.

The copper pipe coil is supplied with water from the mains. The water enters the apparatus at an inlet manifold on the table top. From the inlet manifold, the water flows either through the coil or out through the bypass valve. The bypass valve allows the flow rate and pressure to be controlled independently.

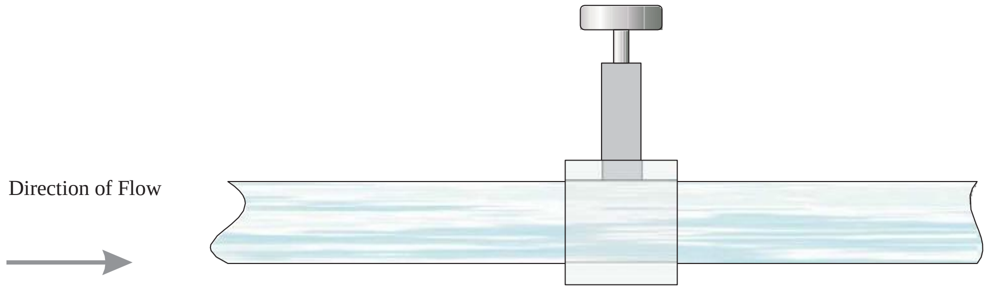
The outlet manifold is fitted with a pressure transducer to measure the pressure changes during the experiment. The water leaves the outlet manifold and passes through a solenoid operated valve, a Bourdon pressure gauge and a manually operated outlet valve. The water then passes through a rotameter type flowmeter to waste.

A separate control box on the working surface supplies power to the solenoid and the optional oscilloscope as well as a connection point for the pressure transducer. The control box includes an output from the pressure transducer suitable for connection to the optional oscilloscope.

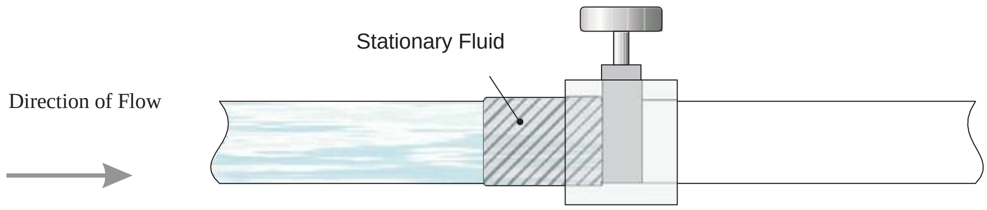
Water Hammer Phenomena

When a domestic tap is turned off quickly it can cause a heavy knocking noise and cause the pipe work to vibrate. This phenomenon is called ‘Water Hammer’.

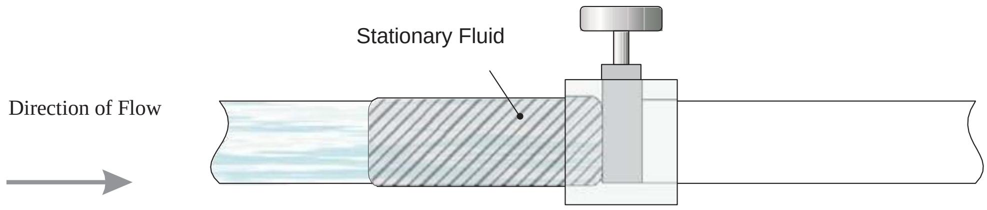
Water hammer occurs when a fluid moving in a pipe is brought to rest suddenly by the rapid closure of a valve for instance. Refer to Figure 2. The fluid immediately upstream of the valve is brought to rest straight away, but the fluid further upstream is initially still moving. This moving fluid compresses the stationary fluid before coming to rest itself, and as a result, a pressure wave moves back upstream. As the fluid is compressed, the pipe will expand slightly as shown in Figure 2. A simple analogy would be a train stopping suddenly. As the railway engine stops, the first carriage will continue moving until its buffers come into contact with those of the engine and the energy is absorbed. The second carriage will do like wise and so on. An effect similar to the pressure wave of Water Hammer will be seen to ripple back down the train.



a) Figure 1 **Valve fully open**



b) Just as the valve closes



c) A fraction of a second after the valve has fully closed

Figure 2 The Water Hammer Phenomena

The pressure wave continues upstream until it reaches a large reservoir, or in the case of the TE86, a section of soft P.V.C pipe. The speed of the pressure wave is equal to the speed of sound in the fluid.

The fluid in the entire pipe is now compressed, but the system is out of equilibrium. To regain equilibrium, the fluid at the reservoir end of the pipe expands out again, causing a flow towards the reservoir, and a negative pressure wave travels back through the pipe in the initial direction of flow. Because this negative pressure wave is associated with a flow towards the reservoir, a negative pressure will occur at the valve as the wave reaches this point. The pressure at the valve continues to oscillate between positive and negative pressures, theoretically as a square wave.

In reality, the negative pressure cannot fall below the vapour pressure of the fluid otherwise cavitation will occur. Friction effects and viscosity will further modify the response away from the theoretical square wave response.

Water hammer is an important consideration in the supply lines of hydropower stations, where the water may travel for a considerable distance, along a pipeline or tunnel, from the supply reservoir to the water turbine. Some means of flow regulation, such as variable gates at the turbine inlet, must be provided to cope with variations in electrical demands. The phenomena is most likely to occur when the electrical load is suddenly rejected, so that the power developed by the turbine is no longer absorbed by the electrical generator. Unless the gates are closed quickly, the turbine and generator would very rapidly overspeed, with potentially disastrous results. On the other hand, rapid gate closure causes severe deceleration of the large mass of water in the long supply pipeline, with the associated danger of extremely high pressure due to water hammer.

A more thorough explanation of Water Hammer can be found in Fluid Dynamics textbooks (see '**Useful Textbooks**').

Technical Data

Item	Specification
Total Length of Apparatus (width)	700 mm
Total Depth (front to back)	950 mm
Total Height	1000 mm
Mains Water Supply*	Minimum 5 L/m @ 3 bar (300 kPa)
Pipe Length (Nominal)**	61 m
Pipe Inside Diameter	0.0127 m
Pipe wall Thickness	0.00119 m
Transducer	6.89 bar (689 kPa) Maximum Pressure
Electrical Supply	
Type	Single Phase
Voltage	230 V (50 Hz) or 110 V (60 Hz)
Current Required	2 A
Fuse	
Main Fuse	2 A Type T 20 mm

NOTE

* The mains water supply pressure is critical on this apparatus. If it is less than the stated values, then the full range of tests cannot be completed.

** This is the nominal pipe length, for an accurate figure, measure the diameter of the coil to the pipe centre line and count the coils - remember toadd the extra lengths of pipe leaving and feeding the coil.

Notation

Item	Symbol	Actual Value	Units
Time	T		seconds
Length of pipe	L		m
Internal Diameter of pipe	d		m
Cross section area of pipe	A		m^2
Wall thickness of pipe	t		m
Pressure, relative to atmosphere	p		N/m^2 (1 bar = 100000 N/m^2)
Density of water	□	1000	kg/m^3
Volumetric Flow Rate	Q		L/min*
Velocity of water	U		m/s
Velocity of pressure wave	c		m/s
Bulk modulus of water	K	0.205 x 10^{10}	N/m^2
Elastic modulus of copper pipe	E	11.5 x 10^{10}	N/m^2

* the flowmeter gives an indication of flow in litres per minute, but most calculations require the SI conversion in m^3/s or L/s

Water Hammer

Aims

This experiment demonstrates the 'Water Hammer' effect and analyses the pressure waves produced inthe pipe.

For this experiment, do not allow the flow rate to exceed 4 L/min, as this willcause a pressure of greater than 6 bar at the pressure transducer and maydamage it. **CAUTION**

Procedure

1. Make sure the apparatus is set up as described in the '**Installation and Assembly**' section.
2. Prepare a blank table of results, similar to Table 7.
3. Switch on the Control Box and the Oscilloscope.
4. Shut the bypass valve and open the outlet valve.
5. Turn on the mains water supply.
6. Wait at least two minutes until all the air has been forced out of the pipe coil and water starts to pass out of the flowmeter. Adjust the bypass valve to obtain a flow rate of 4 L/min.
7. On the oscilloscope, select DEVICE SETTING 'TE86-1' (see **H405A Oscilloscope and Printer** **(optional)** on page 7).
8. Press and hold the solenoid button on the control panel. The pipe may 'jump' as the water flow is stopped by the solenoid and a banging noise may be emitted from the apparatus. A trace will appear on the oscilloscope.
9. Release the solenoid button.

10. Accurately sketch or print the oscilloscope trace (see **H405A Oscilloscope and Printer** **(optional)** on page 7).

11. In your table, record the pressure pulse width and height.

12. Adjust the outlet valve to reduce the flow rate by 0.5 L/min and repeat the procedure.

13. Repeat the procedure until the flow rate is 1.5 L/min.

NOTE

Try the other oscilloscope sweep time/div settings or DEVICE SETTINGS if your trace does not show as much detail as you need.

Recorded Results				Calculated Results			Theoretical Results	
Flow Rate (L/min)	Initial pressure (Bar)	Pulse width (ms)	Pulse height (V)	Flow Velocity ($m.s^{-1}$)	Wave Speed ($m.s^{-1}$)	Pressure pulse (bar)	Pressure pulse (bar)	Wave Speed ($m.s^{-1}$)

Table 7 Blank Table of Results for Water Hammer Experiment

Results Analysis

Use your recorded results and the following equations to complete Table 7.

Calculated Flow Velocity

Calculate the flow velocity (U) of the water from the flow rate (Q) (in L/s or m^3/s) and the dimension of the pipe as follows:

$$U = \frac{Q}{A}$$

Calculated Wave Speed

The measured pulse width represents the time taken for a pressure wave to travel from the solenoid valve to the end of the pipe and back. Use the pulse width as the value of T to calculate the wave speed (c)as follows:

$$c = 2L / T$$

Calculated Pressure Pulse

Use the transducer calibration constant value (V/bar) to convert the pulse height (V) into pulse pressure (bar).

Theoretical Pressure Pulse

Theory shows that the initial pressure pulse (p) may also be calculated from flow velocity, water density and the pressure wave speed as follows:

$$p = U\rho c$$

Compare this to the measured value.

Theoretical Wave Speed

Theory shows that the wave speed may also be calculated from the bulk modulus of water and water density as follows:

$$c = \sqrt{K'/\rho}$$

Where K' is the effective bulk modulus, taking into account the elasticity of the pipe.

$$1/K' = (1/K) + (d/(tE))$$

Calculate the theoretical speed of the pressure wave and compare it to the measured value.

(9) *Francis Turbine*

Introduction

Engineers and students of fluid mechanics need to know how pumps and turbines work and how efficiently they work. This helps them to pick the correct pump or turbine to do the right job.

The Francis turbine is a popular and efficient radial-flow reaction turbine. A British-American engineer -James Francis developed it in 1848, by improving earlier designs by other engineers. It is used in hydroelectric power stations to absorb the energy from falling water in dams and turn electric generators. It is excellent for this purpose because it can also work as a pump to return water to the reservoir if needed.

TecQuipment's Francis turbine (H18) is a laboratory scale, vertically mounted turbine with a band-brake dynamometer that measures torque. It allows students to do tests of performance and efficiency so they can understand how a Francis turbine works. It works with TecQuipment's H1D Volumetric Hydraulic Bench. The bench provides a water supply, flow measurement, a small reservoir area for the turbine outlet and a recirculating water supply. Refer to the User Guide of the Hydraulic Bench for more details.

Description

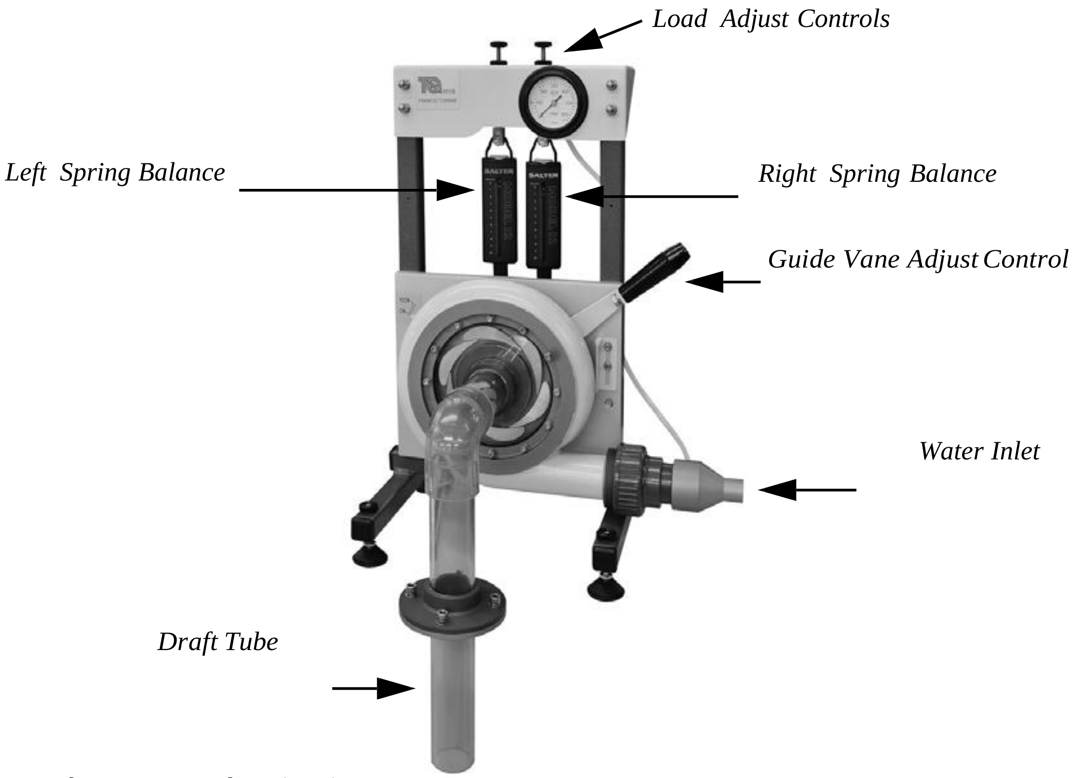


Figure 2 The Francis Turbine (H18)

The Francis turbine is a reaction flow turbine. This means that water passes through it and loses pressure, giving up its energy to the turbine. For best efficiency, engineers put this turbine between the highest pressure water source and a low pressure outlet. It works best with a submerged or 'drowned' outlet, to keep the entire turbine immersed. Textbooks explain why this helps the turbine to work correctly. Also, air pockets can reduce efficiency and cause damage to the turbine.

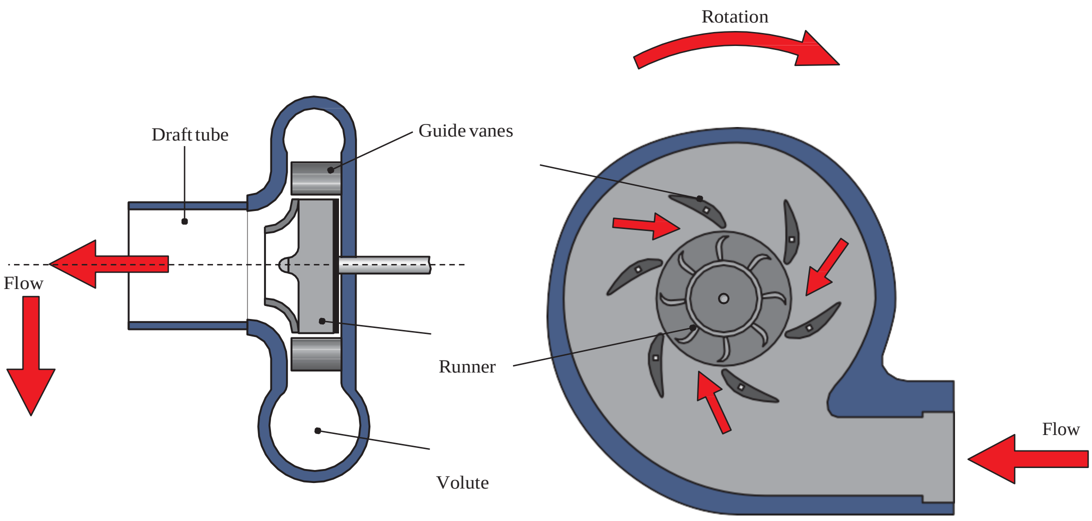


Figure 3 The Francis Turbine

Technical Details

Item	Details
Dimensions	Height (when assembled): 700 mm Width: 400 mm Depth (front to back): 360 mm
Net Weight	11 kg (including weir plate and draft tube extension)
Turbine Type	Francis
Brake (drum) radius	25 mm (0.025 m)
Maximum power output	3 Watts (approximately) (when supplied by a Hydraulic bench)
Maximum speed	Approximately 1100 rev.min^{-1} (when supplied by a Hydraulic bench)
Nominal maximum inlet pressure	0.3 bar (when supplied by a Hydraulic bench)

Notation

Symbol	Description	Units
N	Rotational speed of the turbine	rev.min^{-1}
P_h	Hydraulic Power	W
P_m	Mechanical Power	W
$\square_h$	Hydraulic Efficiency	%
T	Torque	Nm
p	Pressure	Pa (pascals)
Q_v	Volume Flow	L.s^{-1} or m^3.s^{-1}
R	Radius	m
A	Left spring balance reading	N (Newton)
B	Right spring balance reading	N (Newton)
F	Force	N (Newton)

Useful Equations

Mechanical Power

This is the power absorbed by the turbine, taken from the water.

$$P_m = \frac{2\pi\ N\ T}{60}$$

Hydraulic Power

This is the power in the water delivered to the turbine. It is simply a product of the flow through and pressure into the turbine. Normally you would use volume flow ($m^3.s^{-1}$) and this equation:

$$P_h = Q_v p$$

However, for simplicity and as the volumetric hydraulic bench measures volume flow in litres, this equation (with volume flow in litres) is more useful:

$$P_h = \frac{Q_v p}{1000}$$

Torque (T)

This is the torque measured by the two spring balances. The balances measure the turning force on the drum at the back of the turbine (see Figure 10). The total force is the difference between the readings. Due to the direction of rotation, the right hand balance will give a larger reading than the left hand balance, so for simplicity:

$$F = B - A$$

The torque is the radius of the drum multiplied by the force:

$$T = R * F$$

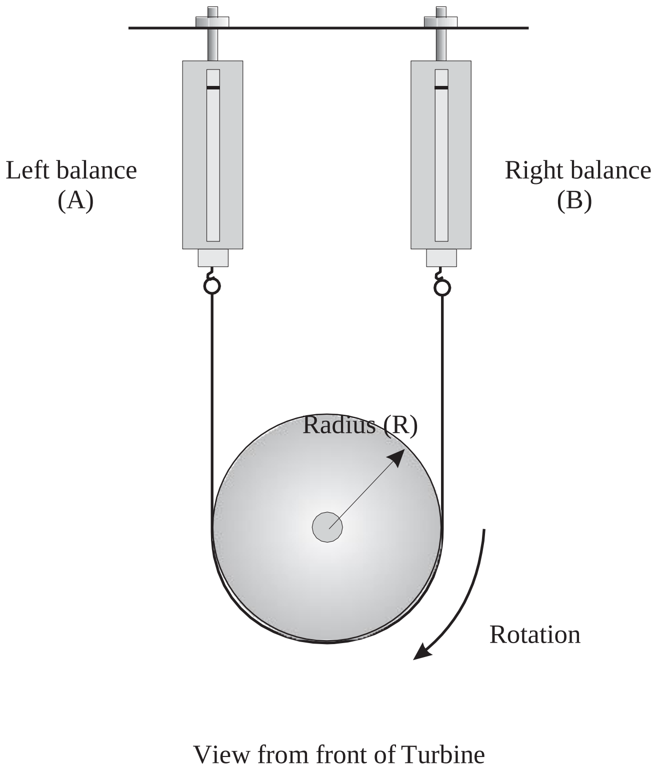


Figure 10 Torque Measurement

Hydraulic Efficiency

This is a ratio of the mechanical power measured at the turbine divided by the hydraulic power input tothe turbine:

$$E=(p_m/p_h)*100$$

Efficiency (constant inlet pressure)

Aim

To find the power in the water delivered to the turbine, and the power absorbed by the turbine tocalculate the maximum efficiency of the turbine.

Procedure

1. Create three blank results table, similar to Table 2.

Inlet Pressure Guide Vane Setting							
Left Balance (N)	**Right Balance (N)**	**Flow ($m^3.s^{-1}$)**	**Speed ($rev.min^{-1}$)**	**Load (Torque) (Nm)**	**Mechanical Power Absorbed (W)**	**Power in the Water (W)**	**Efficiency(%)**

Table 2 Blank Results Table

2. Fully open the guide vanes (to the 100% position).

3. Adjust the spring balances to give no load and make sure that they show 0 (zero).

4. Set the H1D to give full flow and leave the turbine running for a few minutes.

5. Adjust the flow from the bench to give an inlet reference pressure of 0.1 bar (10000 Pascals or 0.01 MPa). Measure and record the flow.

6. Use the optical tachometer to measure the maximum (no-load) speed of the turbine. To do this, put the tachometer against the clear window at the back of the turbine and use it to detect the reflector on the drum.

7. In steps of 0.5 N load on the right hand spring balance, slowly increase the load until the turbine stops. At each step, adjust the flow from the H1D to keep the pressure at the reference value, then record the turbine speed and water flow.

8. Repeat the test for the 2/3 (66%) guide vane setting.

Results Analysis

For each guide vane opening, use your results and the equations in the **Theory** section to calculate torque, power absorbed by the turbine and water power.

For each guide vane setting, produce charts of efficiency (vertical axis) against speed (horizontal axis) and efficiency against flow.

(10) *INVESTIGATION OF RECTANGULAR FLOW CHANNEL*

Cussons P6255 Flow Channel is designed to allow a series of experiments on water flow through a rectangular channel to be conducted. The channel is of rectangular cross section 175mm high x 55mm wide and 2500mm long. The channel walls are made of a clear acrylic plastic to ensure a clear view of the various flow regimes which can be generated. The flow channel incorporates a specially designed entry section which incorporates a stilling pond, filled with glass spheres, to provide smooth non turbulent flow conditions at entry to the channel. At the discharge end of the channel an adjustable undershot sluice gate is provided which can be used to control the exit flow.

Figure 1. Schematic of Flow Channel

The channel is supported on a steel framework which incorporates a variable height support at the right hand end allowing the slope of the channel to be varied. A measuring point is provided together with a clock distance gauge and the calibration is such that 1 revolution of the clock dial is equivalent to a slope of 1:1500.

Cussons P6255 Flow Channel is intended to be used with Cussons P6100 Hydraulics Bench, the hydraulics bench providing a pumped water supply to the flow channel and the means of measuring the flow rate. The flow channel should be positioned on the left hand side of the hydraulics bench in a position such that the discharge from the flow channel will flow into the weir channel on the hydraulics bench. The output connection from the hydraulics bench should be connected to the inlet connection pipe of the flow channel, which is physically located under the channel.

Objective

- To observe the hydraulic jump phenomenon;
- To compare measured flow depths with theoretical results;
- To become familiar with the rectangular open channel apparatus.

Theory

The hydraulic jump is a phenomenon which results from limiting the upstream flow of water with a sluice gate, leading to a shallow and rapid supercritical flow, and limiting the downstream flow with a weir, which causes the water in front of it to pile up and form a subcritical flow. The transition region between these two is the hydraulic jump, where the flow of water is observed to suddenly rise from super- to subcritical levels. It is similar to the meeting of two flows of different speeds at a point, causing a shock front.

During the hydraulic jump, a large amount of energy is lost as heat. This means that the head loss is unknown, but not negligible. Therefore, the equations used to model this phenomenon are the momentum and flow continuity equations.

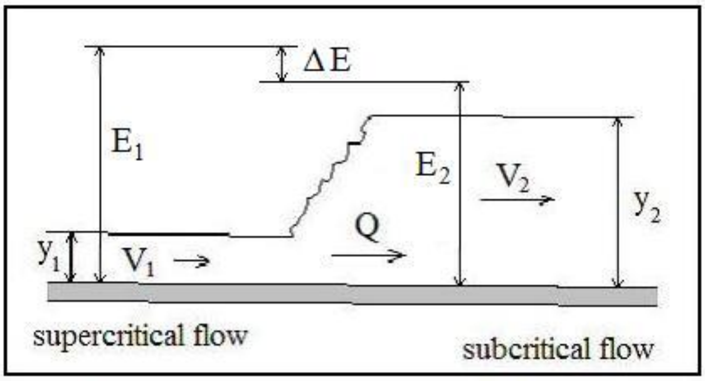


Figure 1: Hydraulic jump illustration.

$Flow\ continuity: Q = bV_1h_1 = bV_2h_2$

$Momentum: \frac{1}{2}\rho g h_1^2 - \frac{1}{2}\rho g h_2^2 = Q(V_2 - V_1)$

$M = \frac{V^2 h}{2g} + \frac{h^2}{2}$

The upstream and downstream flow depths can be related by:

$$\xi = \frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8Fr_1^2} - 1\right)$$

Each flow has a specific velocity and depth, from which we can calculate a factor called Froude's number (Fr):

$$Fr = \frac{V}{\sqrt{gh}}\ ;\ Fr_1 = \frac{V_1}{\sqrt{gh_1}} > 1\ ;\ Fr_2 = \frac{V_2}{\sqrt{gh_2}} < 1$$

Head losses can be found by applying conservation of energy for the open channel flow problem as:

$$h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + h_L$$

Procedure

1. Connect the hydraulic bench to the flow channel apparatus and allow the water to flow at 1.5 L/s;
2. Install the sluice gate at a point in the first segment of the channel, adjust the height by turning the knob;
3. Adjust the second sluice gate at the end of the channel in the same way, until a hydraulic jump forms between the two sluice gates;
4. Measure the water depth at each side of the jump, and record the results as well as the flow rate.

Data

Table 1: Measured water depths and gate opening.

Gate opening, h_g (m)	Initial depth, y_1 (m)	Sequent depth, y_2 (m)

Table 2: Constants and data used in calculations.

Flow rate, Q (m^3/s)	
Width of channel, b (m)	0.078 m

Results

Table 3: Results and calculations

Initial depth, y_1 (m)	Seq. depth, y_2 (m)	y_2/y_1 prac.	V_1 (m/s)	V_2 (m/s)	Fr_1	Fr_2	Y2/y1 theo.

E_1 (m)	E_2 (m)	$\Delta E_{prac.} = E_1 - E_2$	$\Delta E_{theor.}$

Draw Energy VS Depth Curve and find energy loss

Find E_{min}

$$y_c = \sqrt[3]{\frac{Q^2}{gb^2}}$$

The corresponding minimum energy value is calculated using this depth and the following equations:

$$V_{min} = \frac{Q}{b \times y_c}; E_{min} = \frac{V_{min}^2}{2g} + y_c$$

Critical depth, y_c (m)	
Minimum velocity, V_{min} (m/s)	
Minimum specific energy, E_{min} (m)	

Equations:

$$Flow\ velocity, V\left[\frac{m}{s}\right] = \frac{Q}{b \times h}$$

$$Froude's\ number, Fr = \frac{V}{\sqrt{gh}}$$

$$Ratio\ of\ depths, \frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8Fr_1^2} - 1\right)$$

$$Specific\ energy, E\ [m] = y + \frac{V^2}{2g}$$

$$Theoretical\ energy\ loss, \Delta E_{theor}[m] = \frac{(y_2 - y_1)^3}{4y_1y_2}$$

$$Experimental\ energy\ loss, \Delta E_{prac}[m] = E_1 - E_2$$

$$Critical\ depth, y_c[m] = \sqrt[3]{\frac{Q^2}{gb^2}}$$

$$Minimum\ velocity, V_{min}\left[\frac{m}{s}\right] = \frac{Q}{b \times y_c}$$

$$Minimum\ specific\ energy, E_{min}[m] = \frac{V_{min}^2}{2g} + y_c$$

Reading	Channel bed slope	Flow Rate M^3/s	depth	Wetted perimeter	Hydraulic Radius	Flow Velocity	Manning roughness coefficient	Chezys roughness coefficient
1								
2								
3								
4								
5								
6								
7								