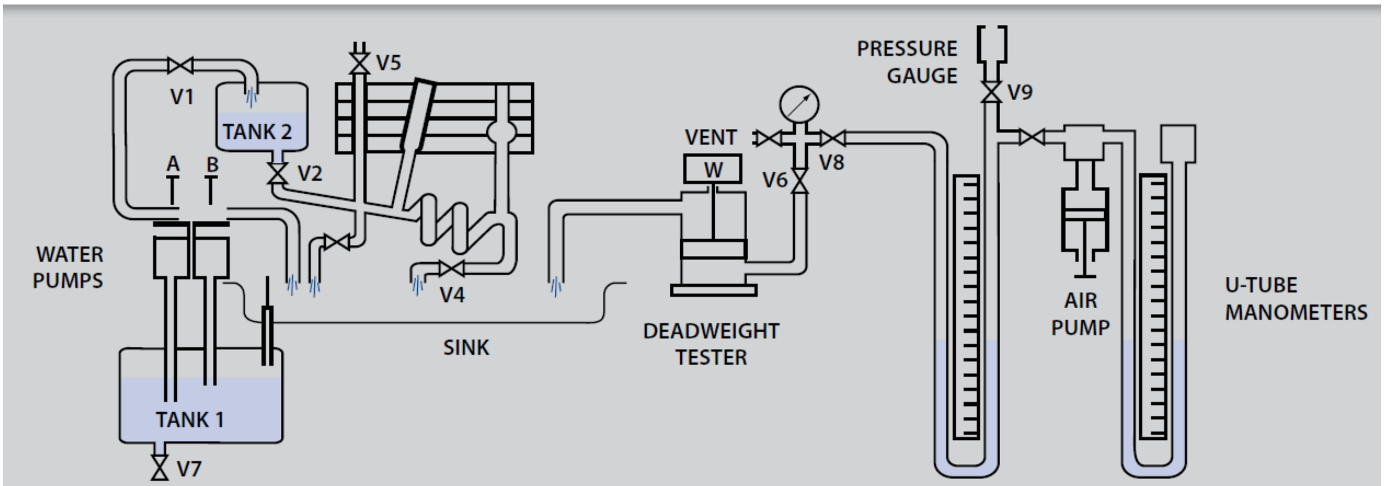
Experiment No.1: Fluids Properties

1: Measurement of density and specific gravity
2. Study of the effect of capillary elevation between flat sheets
3: Study and measurement of the effect of capillary elevation inside capillary tubes
4: Study of Archimedes' principle
5: Measurement of the viscosity of a fluid using a sphere viscometer
The module consists of a series of elements to study the main properties of fluids separately.



Pressure and liquid level experiments are conducted using a built-in pipe system shown in outline in this diagram

TECHNICAL SPECIFICATION

Universal hydrometer:	Range 0.70-2.00 subdivided in 0.01 intervals
Falling sphere viscometer:	40mm tube diameter
Hydrostatic pressure apparatus:	Comprises counterbalanced precision quadrant pivoted on knife edges at its centre of arc
Direct reading barometer:	With compensated silvered metal scale Range 585-790mm subdivided in 1mm intervals Includes thermometer
100mm dial pressure gauge:	Range 0-200 kN/m2 (kPa) and equivalent head of water in metres
Deadweight pressure gauge calibrator:	With 2 x 0.5kg, 1kg and 2.5kg weights
Lever balance:	178mm diameter pan, hook for use in buoyancy experiments, antiparallax cursor, double scale 0-0.25kg and 0-1.00kg
Thermometer:	Range -10˚C to +50˚C

Practical possibilities

- Study of the effect of capillary elevation between flat sheets.
- Study and measurement of the effect of capillary elevation inside capillary tubes
- Study and verification of Archimedes principle using a bucket and a cylinder with a lever balance.
- Measurement of the density of a fluid and the relative density of a liquid using a hydrometer and a pycnometer.
- Measurement of the atmospheric pressure using a barometer.
- Measurement of the temperature of a fluid using an alcohol thermometer.
- Measurement of the viscosity of a fluid using a sphere viscometer.

1- Density

Density is defined as the amount of mass of a substance contained per unit volume. It can be expressed as mass density, relative density, specific weight or specific volume. Mass density, ρ, is defined as the mass of a substance per unit volume. Units in the SI are kg/m^3.
It must be taken into account that the density of a liquid is practically constant, since the volume occupied by a given mass of a liquid is almost invariable. But in the case of gases, density varies depending on the volume occupied (for a mass of such a gas). As a result of that, a liquid can be considered virtually incompressible (except when it is working in critical conditions), while gases are compressible.

Specific gravity or **relative density** of a fluid is defined as the quotient between the density of a substance and a standard value; therefore, it has no units. Generally, it is only used in liquids and solids. A common standard is the maximum density of water to atmospheric pressure, which corresponds to a temperature of 4ºC.

$$S = \frac{\text{mass of given fluid}}{\text{mass of water (same volume)}}$$

If V is the volume of a liquid and Vw the volume of water, ρl is the density of the liquid and ρ_w is the density of water, then:
The two previous properties can be studied using the hydrometer placed in the left hand end of the front panel.

The operation of the hydrometer is based on Archimedes´ principle, which states that when a body is submerged into a liquid it becomes subject to a vertical force equal to the weight of the liquid the body displaces.

Thus, a simple hydrometer consists of a glass tube closed by an end and with a scale inside.
A small amount of lead, sand or mercury is placed at the bottom for preventing flotation.

Experimental procedure

- Fill a hydrometer jar with water to make the hydrometer float inside. Check that the length immersed corresponds to 1.00 in the graduated scale.
- Fill other hydrometer jar with another liquid and record the value indicated in the graduated scale for each liquid used in the test.
- The specific density is indicated by this value on the scale. Density will be calculated from that value.
- Repeat the test using a pycnometer this time:
  - Weight the pycnometer empty.
  - Fill the pycnometer with the liquid up to the indicated level (50 ml).
  - Weight the pycnometer
  - The exact weight of the 50 ml. of liquid will be obtained by calculating the difference between both weights.
  - The density value is obtained with the liquid volume value and its weight. The specific density will be calculated from that value

Tables and results

- Calculate density from the relative density value obtained with the hydrometer, or vice versa if the pycnometer has been used.
- Record the results obtained in the plot below taking into account the values of the atmospheric pressure and the temperature at the moment the practical exercise was performed.
- Complete data in the following table:

Liquid	Specific density	Density
Water		
Glycerin		
Engine oil		

2-Viscosity measurement

When the ball is moving at a constant velocity, u, inside the liquid, the forces acting on them are:

a) The gravity of the ball (Fg =m . g)

b) The buoyant force Fe

c) The viscose resistance to motion Fv

Since the falling velocity of the ball is constant, the algebraic sum of these forces must be zero:

$mg - F_e - F_v = 0$

$$\rho_B \cdot g \cdot \frac{4}{3}\pi \cdot r^3 - \rho_l \cdot g \cdot \frac{4}{3}\pi \cdot r^3 - 6\pi \cdot \mu \cdot r \cdot u = 0$$

$$\mu = \frac{4\pi \cdot r^3 \cdot g}{18\pi \cdot r \cdot u}(\rho_B - \rho_l) = \frac{2}{9}r^2 \cdot g \frac{(\rho_B - \rho_l)}{u}$$

Measurement of the viscosity of a fluid using a sphere viscometer

- Calculate the density of the test liquid, for example using a pycnometer, following the procedure described in the practical exercise 1
  - Fill the viscometer with the test liquid whose viscosity is going to be determined.
  - Observe the marks on the viscometer and select two of them. The upper mark will be the place from which the falling time will be measured and the lower mark will indicate the end of the falling time.
  - Set the chronometer to zero and put the ball at the upper side of the tube.
- Release the ball and start the chronometer when the ball passes through the upper mark. Stop the chronometer when the ball passes through the lower mark. Record the time required by the ball to travel the distance from the upper mark to the lower mark.
- Repeat the same operation with the other balls.
- Complete the data in the table below:

Fluid	Diameter of the ball	Distance travelled (mm.)	Time used (sec.)	Velocity of the ball (m/s)

(*) Density of the balls made of INOX AISI 304 steel: 7.91 gr/ cm^3

3- Capillarity

When a small diameter glass tube is introduced into a liquid, the level shall go up or down depending of the contact angle between the liquid surfaces. In liquids as water, which wets the tube, the result is a level increment, meanwhile in liquids that do not wet the tube, as mercury, the result is just the opposite.
Gravity exerted on the risen liquid column must be supported by the surface tension, which acts along the perimeter of the tube. Thus,

$$\rho\, g\, h \frac{\pi\, d^2}{4} = d(\cos\theta)\sigma\pi$$

$$h = {(4\,\sigma\cos\theta)}/{\rho\, g\, d}$$

If the liquid wets the wall of the tube, the angle θ is zero, thus:

$$h = {4\,\sigma}/{g\, d\, \rho}$$

Study of the effect of capillary elevation between flat sheets

- Clean both glasses thoroughly.
- Loosen the screws slightly and place a strip of paper between the glasses vertically.
- Tighten the screws carefully.
- Place the two glasses in the support guides.
- Submerge it in water.
- Observe that where the space is smaller the elevation is higher and where the space is bigger the elevation is lower.
- Do the same thing with other strips of different thickness.

Study and measurement of the effect of capillary elevation inside capillary tubes

- Make sure that capillary tubes are clean.
- Place the board in a vessel with a specific level of water and introduce the capillary tubes
- Place a piece of card between the capillary tubes.
- Mark the cardboard at the height of the capillary elevation in each tube.
- Measure the capillary increment "h" in each tube

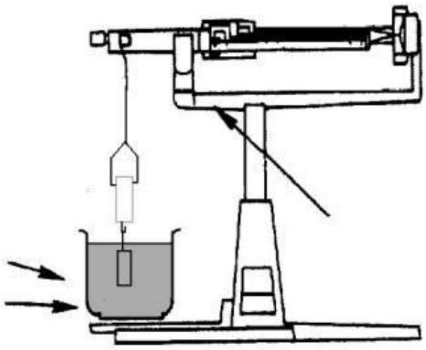
Complete the following table and compare the values measured and values technically calculated by capillary elevation.

Diameter of the tube	Average capillary elevation h (mm)	Theoretical capillary elevation h (mm)
5 mm.		
4 mm.		
3 mm.		
2.2 mm.		
1.7 mm.		
1.2 mm.		

(*) Surface tension of water is 0.074 N/m.

4- Archimedes principle

The physical principle is: *“any body wholly or partially immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object*”. This force is called Archimdes or hydrostatic lift force and is measured in Newton (S.I).



Archimedes’s principle formula is: $$E = m \cdot g = \rho_l \cdot V \cdot g$$

where: V = volume of fluid displaced by an object partially or totally immersed in the fluid

Study of Archimedes’ principle

- Put the unit on the table and, using a hook, hang the bucket and cylinder with a thin thread from the lower side of the arm, recording the weight of the cylinder and the bucket
- Prepare the scale to measure between 0 and 0.25 Kg.
- Immerse the cylinder in a vessel with water completely and record the weight again.
- Remove the cylinder and the vessel with water and record only the weight of the bucket.
- Fill the bucket with water and record its weight

  Mass of the bucket with the cylinder m1 =................. g.
  Mass of the bucket with the cylinder submerged in water m2 = ... g.
  Mass of the bucket m3 = ... g.
  Mass of the bucket full of water m4 = ... g.
  From these results, verify that:
  $m_1 - m_2 = m_4 - m_3$

Manometers

Description

The unit consists of a vertical tank made of PMMA (methacrylate) that contains the water and connected to different vertical manometric tubes. It includes two parallel manometric tubes, one "U" shaped tube, one variable transverse section tube that allows to demonstrate that the level of a free surface is not affected by the size or the shape of the tube and a manometric tube with a rotation system from the base that allows to incline its angle up to 90º. These tubes can be used either individually or combined for the diverse demonstrations. The tank made of PMMA includes a Vernier point and hook gauge mounted on the tank's cover. It allows to measure great changes in the water level with more accuracy than with a simple scale.

A transparent piezometric tube with variable height placed through the tank's cover allows to observe the static load above the water when the air space above the water is not open to the atmosphere. For that purpose, a plug that fits the tank's cover perfectly is supplied.

The unit allows to add a small water flow through a pipe that connects the manometric tubes to study the effect of friction created by the fluid motion.

A manual pump can be connected to both the water tank and each manometric tube, allowing to vary positive or negatively the static pressure of the air as required for several demonstrations.

Specifications

- Anodized aluminum frame that guarantees a good stability and resistance to the environment.
- Tank made of PMMA (methacrylate) of 100 mm of diameter and 575 mm of depth.
- Manometric tubes of 460 mm of length:
- 1 "U" shape vertical tube.
- Two parallel vertical tubes.
- One vertical tube with variable section.
- One vertical tube with a pivot that allows it to incline from 0 to
- 90º.
- Vernier hook and point gauge.
- Piezometric tube.
- Manual air pump.
- Purge valve.
- Plug to close the tank so that it is not open to atmospheric pressure

Some properties of pressure in static fluids are:

- Pressure at a point of a fluid at rest is the same in all directions (Pascal principle).

- Pressure in all points located in the same horizontal plane within a fluid at rest (and located in a constant gravitatory field) is the same.

- In a fluid at rest, the contact force exerted inside a fluid by one part of that fluid on the other part is normal to the contact surface.

- Force associated to pressure in an ordinary fluid at rest is always directed towards the outside of the fluid. Therefore, due to the action-reaction principle, it results on a compression for the fluid, it never results in traction.

- The free surface of a liquid at rest (located in a constant gravitatory field) is always horizontal. This is true only on the Earth surface and to the naked eye, since the action of gravity is not constant. If there are no gravitatory actions, the surface of a fluid is spherical and, therefore, not horizontal.

In fluids at rest, any point of a liquid mass is subjected to a pressure in function of only the depth to which that point is located. Other point at the same depth will have the same pressure. The imaginary surface that crosses both points is called pressure equipotential surface or isobaric surface.

Calculation of the hydrostatic pressure

Hydrostatic pressure in a point inside a fluid at rest is directly proportional to the density of the fluid, ρ, and to the depth, h.

$$P_h=\rho.g.h$$

Hydrostatic pressure only depends on the density of the fluid and the depth (g is constant and equal to 9.8 m/s^2).

Observe points A and B in the following figure. Δh is the depth difference between them, Δh=(hB – hA):

$$P_A=\rho.g.h_A \quad \text{(pressure of A)}$$
$$P_B=\rho.g.h_B \quad \text{(pressure of B)}$$

The pressure difference between both points is obtained by subtracting these equalities:

$$P_B- P_A= (P_B=\rho.g.h_B) – (P_A=\rho.g.h_A) =\rho.g.(h_B-h_A)= \rho.g.\Delta h$$

Devices to measure hydrostatic pressures

Pressures generated by a liquid at rest can be determined by using some devices commonly called manometers. These elements are based on the following equation:

$$P=P_a+ \gamma.Z$$

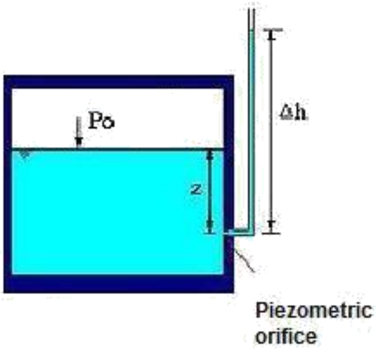
Where:
P: pressure that interests us (absolute pressure).
Pa: atmospheric pressure exerted over the free surface of the liquid.
Z: depth to which the pressure exerted by the liquid wants to be known.

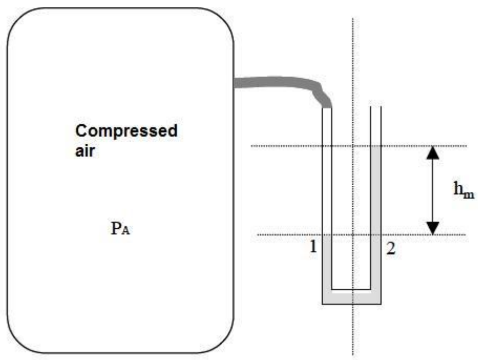
γ: specific weight of the liquid under study.

Bourdon manometer. High pressures and great ranges of pressure are always measured with metallic manometers, Bourdon type manometers. The figure below shows a diagram of one of these manometers, where it can be observed that pressure produces a deformation in a curve tube or spiral (Bourdon tube) whose motion is transferred through gears in a graduated scale.

Pressure transducers. They are those devices in which the pressure measured is read with the help of an electric circuit in a numerical display. They are based on electrical signals, although the principle by which they measure pressure is based on the deformation or
elongation of a conductive elastic material by the action of a force transmitted through an elastic membrane in contact with the fluid.

U tube manometer. They are used for low pressures. They are U shaped glass tubes that are filled with a fluid of known density and immiscible with the fluid whose pressure wants to be measured. To measure the pressure at one point of the conduction, one of its branches is connected to it and the other one with the atmosphere (it gives the over atmospheric pressure or gage pressure). To measure the pressure difference between two points, each branch of the U tube is connected with the corresponding points of the pipe.





Points 1 and 2 of the manometer have the same pressure, since the same manometric fluid at rest is at the same height (P1 = P2). Neglecting the hydrostatic pressure exerted by the gases (it is equivalent to neglect its potential energy) only air compressed in the tank with its PA pressure will exert pressure on point 1. Thus, a mercury column of h_m height and the atmospheric pressure over it (since this branch is open) exert pressure on point 2. Then:

$$P_A = \rho_m.g.h_m + P_{atm}$$

Piezometric tube

A piezometric tube is, as its name indicates, a tube connected to a vessel containing a fluid where the level rises up to a height equivalent to the pressure of the fluid at the connection point or piezometric orifice, that is to say, up to its load level. Pressure P can be expressed according to the hydrostatic equation as:

$$P = P_0 + \rho.g.z = \rho.g.\delta h$$

Experimental procedure

A-Use of a piezometric tube to measure pressure

It is necessary to put the plug in the tank so that air cannot leak through the orifice, being able to pressurize the tank with a manual pump.

1. Close all the valves of the tubes manifold.

2. Fill the tank until the lower part of the piezometric tube is in contact with water.

3. Connect the pump to the upper plug of the tank with the non-return valve in the correct direction and pressurize the tank.

4. Observe if the water head in the piezometric tube rises. If it does, observe that the level is kept constant when we stop to pressurize with the pump.

B- Measurement of the liquid level by using a Vernier hook and point gauge

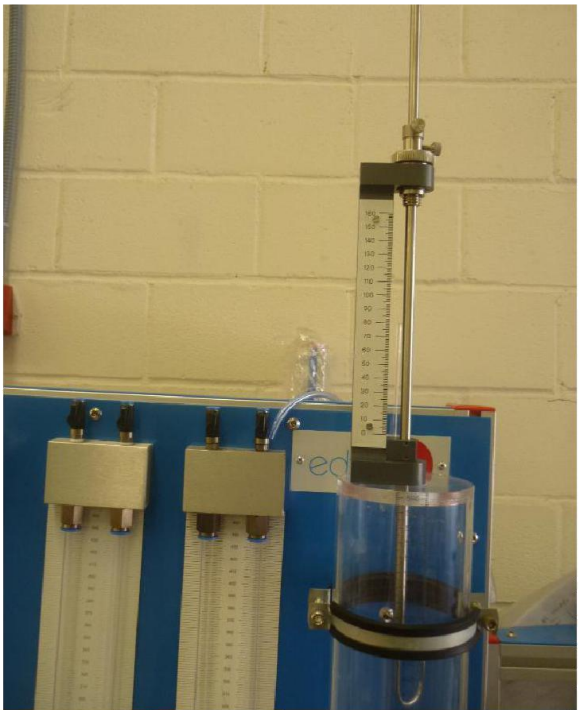
1. Close all the valves of the manifold that connect the tank to the manometric tubes so that water in the tank cannot leak.

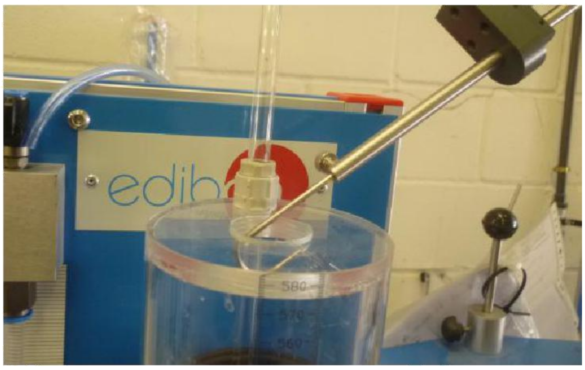
2. Fill the tank with water up to the desired level and check that the level does not vary.

3. Use the gauge in such a way that the point of the hook indicates the current water level in the tank. Record the value indicated on the scale of the gauge.

4. Open one of the manifold's valves to fill one of the manometric tubes, decreasing the water level in the tank.

5. Regulate the gauge until the point returns to the water level. Record the level change.





C-Use of manometric tubes to measure the differential pressure

1. The U shape tube will be used to carry out this practical exercise. Let water enter this tube and close its manifold valve so that water cannot leak.

2. Connect the manual pump to one of the upper valves of the U tube. Make sure that the other valve is closed.

3. Introduce pressure with the pump so that the water head in the tubes varies, creating a pressure difference in the tube.

4. Close the valve to which the pump is connected and disconnect the pump. Record the pressure difference measured.

5. For a different pressure, open slightly the valve and record the new value.

D- **Use of an inclined manometer with different slopes**

1. Before starting, make sure that only the valve of the manifold that corresponds to the inclined tube is open. Besides, open the upper valve of the inclined tube to let the air leak through that end.

2. Place the inclined tube in vertical position, where the measurement of the angle indicates an slope of 0º. Record the water level in the tube.

3. Change the slope of the tube up to 10º. Record the value of the water level.

4. Repeat the operation at intervals of 10º until reaching 90º of slope or until water leaks through the inclined tube.

E- **Demonstrating that the level of a free surface is not affected by the size or the shape of the tube**

1. Fill the water tank up to a specific level. Do not put the plug or the gauge for this practical exercise. The tank must be free to add more water during the experiment.

2. Open the valves of the manifold that correspond to the variable section and parallel tubes. Besides, open the upper valves of both tubes.

3. Observe that the water level in these two tubes coincides with the level in the water tank.

4. Repeat the experiment with different levels in the tank, adding more water from the beakers.

Experiment 2: Buoyancy and Stability of a Floating Body

1. Objectives

- Determination of center of buoyancy
- Determination of metacentric height
- Investigation of stability of floating objects

2. Apparatus

The rectangular pontoon is fitted with a vertical sliding weight

[2] transparent floating body with rectangular frame cross-section
[3] one horizontally movable clamped weight for adjusting the heel
[4] one vertically movable clamped weight for adjusting the center of gravity
[5] clinometer with scale for displaying the heel
[6] other floating bodies with different shapes of frame available as accessories: HM 150.39

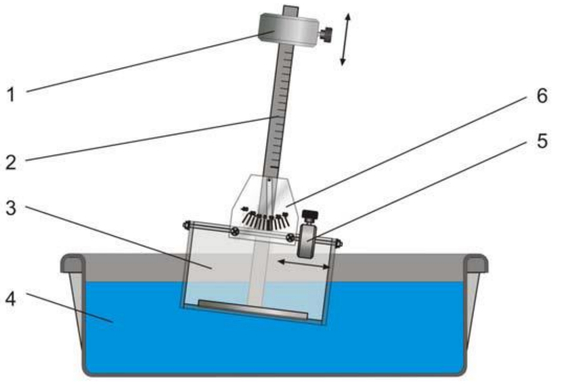


Figure 1- Different parts of experimental apparatus HM 150.06

Horizontal scale: 180mm
Vertical scale: 400mm
Height scale of the floating body: 120mm
Clinometer scale: +/- 35°

Weights

- floating body without clamped weights: approx. 2608g
- vertical clamped weight: 580g
- horizontal clamped weight: 194.6g

Tank for water: 50L

3. Theory

Floating bodies are a special case; only a portion of the body is submerged, with the remainder poking of the free surface. The buoyancy, FA, which is the weight of the displaced water, i.e., submerged body portion, is equal to its dead weight, FG. The center of gravity of the displaced water mass is referred to as the center of buoyancy, A and the center of gravity of the body is known as the Centre of mass, S.

In Equilibrium position buoyancy force, FA, and dead weight, FG, have the same line of action and are equal and opposite (see Fig. 2). A submerged body is stable if its center of mass locates below the center of buoyancy. However, this is not the essential condition for stability in floating objects.

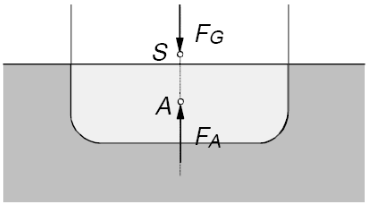


Figure 2- Buoyancy force and center of buoyancy.

A floating object is stable as far as a resetting moment exists in the event of deflection or tilting from the equilibrium position. As shown in Fig. 3, dead weight FG and buoyancy FA form a force couple with the lever arm of b, which provides a righting moment. The distance between the center of gravity and the point of intersection of line of action of buoyancy and symmetry axis, is a measure of stability. The point of intersection is referred to as the metacenter, M, and the distance between the center of gravity and the metacenter is called the metacentric height zm.

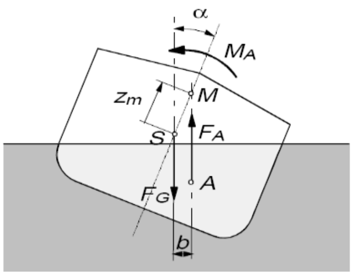
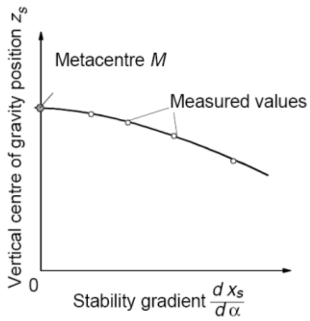


Figure 3- Metacenter and metacentric height.

The floating object is stable when the metacentric height zm is positive, i.e., the metacenter is located above the center of gravity; else, it is unstable.
The position of the metacenter is not governed by the position of the center of gravity. It merely depends on the shape of the portion of the body under water. There are two methods of determining the metacenter position.
In the first method, the center of gravity is laterally shifted by a certain constant distance, xs, using an additional weight, causing the body to tilt. Further vertical shifting of the center of gravity alters the heel angle α. A stability gradient formed from the derivation $dxs/d\alpha$ is then defined which decreases as the vertical center of gravity position approaches the metacenter. If center of gravity position and metacenter coincide, the stability gradient is equal to zero and the system is stable. This problem is easily solved graphically (see Fig. 4). The vertical center of gravity position is plotted versus the stability gradient. A curve is drawn through the measured points and extrapolated as far as it contacts the vertical axis. The point of intersection with the vertical axis locates the position of the metacenter.



For the experimental setup of Fig 5, the first step is to determine the position of the overall center of gravity xs, zs from the setting positions of the sliding weights. The horizontal position is referenced to the centerline:

$$x_s = \frac{m_h x}{m_h + m_v + m} = \cdots \ldots \ldots . x$$

The vertical position is: zg=6,7cm

$$z_s = \frac{m_v z + (m + m_h) z_g}{m_h + m_v + m} = \cdots \ldots \ldots + \cdots \ldots . . \mathrm{z}$$

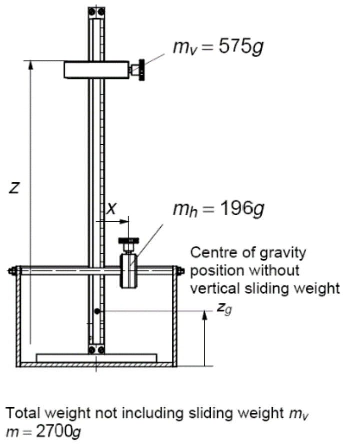


Figure 5- Position and size of sliding weights

And the stability gradient is: $dxsd\alpha{=}xs$

$$\frac{dx_s}{\mathrm{d}\alpha} = \frac{x_s}{\alpha}$$

4. Procedure

Set the horizontal sliding weight to position x = 8cm.
Move vertical sliding weight to bottom position.
Fill the tank with water and insert the floating body.
Gradually raise vertical sliding weight and note down the tilting angle.
Plot stability gradient versus vertical center of gravity position and using the plot determine the metacentric height. Compare the result with the metacentric height calculated from Eq. (1).
Raise the vertical sliding weight until the floating apparatus reach the instability point and record this data point. Compare it with your previous results.

5-Discussion

1- What will happen if the center of gravity and the center of buoyancy of a floating object are the same?

2- When and why will the floating object become unstable? Compare theoretical expectations to your lab observations and discuss any differences.

3- Derive and measure the buoyancy force exerted to the experimental setup when the vertical weight is at the bottom and the horizontal weight is at the center.

4- Derive equations (2) and (3).

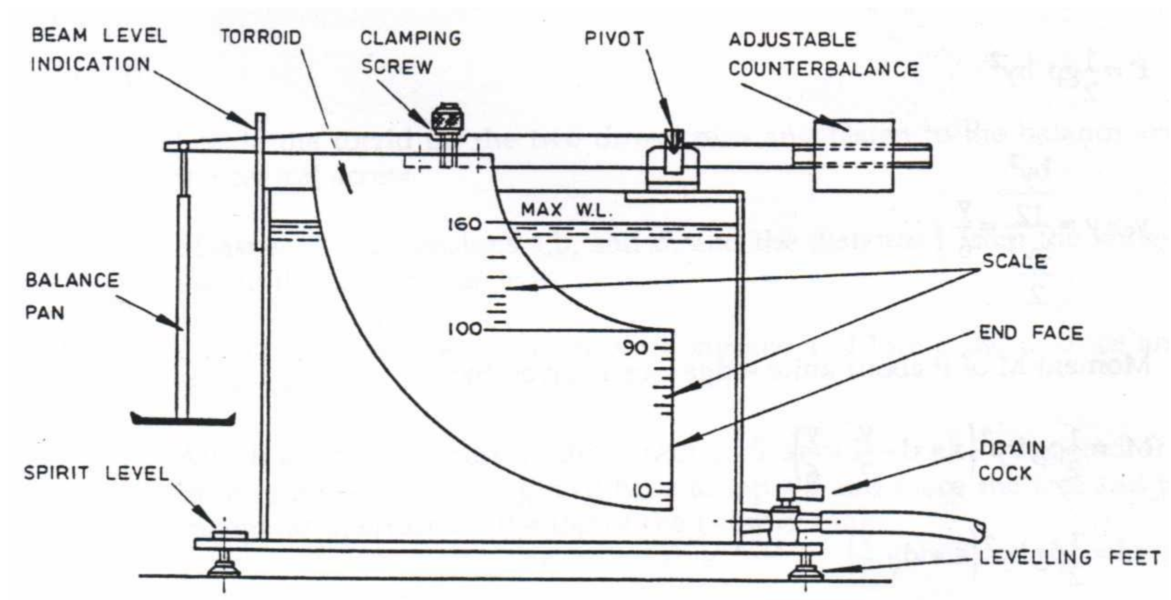
Experiment 3: Center Of Pressure On A Plane Surface

I. OBJECT

To determine the position of the centre of pressure on the rectangular face of the toroid.

II. APPARATUS

Hydrostatic Pressure Apparatus



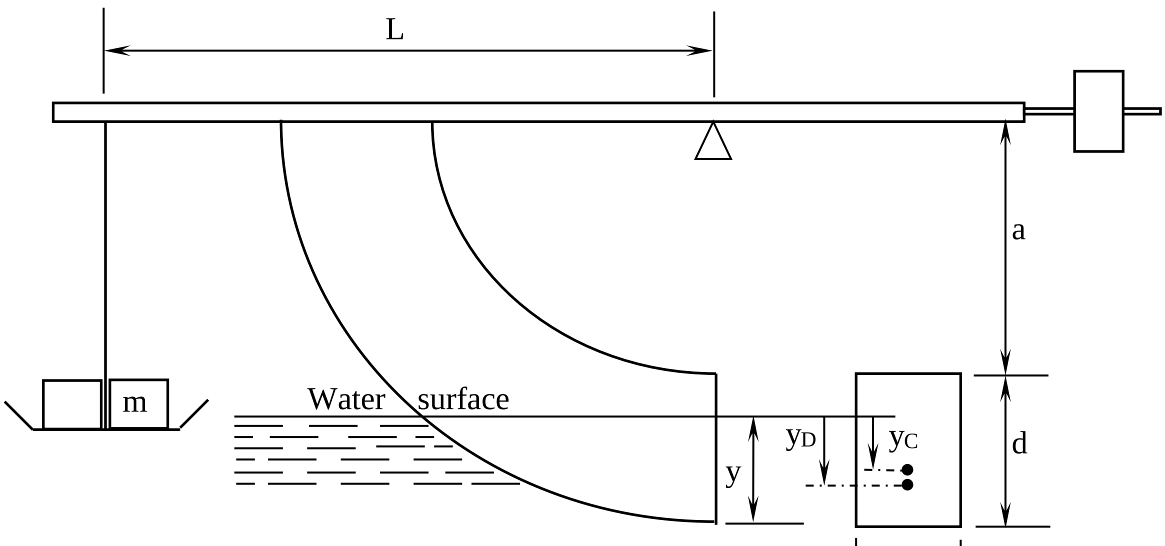
III. ANALYSIS

Hydrostatic force acting on the rectangular face:

$$P = \rho g h_C A \qquad (1)$$

and its center $y_D = y_C + \dfrac{I}{y_C A}$ (2)

- **Partial immersion**



$h_C = y_C = \dfrac{y}{2}$; A = b.y (3)

Hence $$P = \frac{1}{2}\rho g b y^2 \tag{4}$$

$$y_D - y_C = \frac{by^3/12}{by^2/2} = \frac{y}{6} \tag{5}$$

Moment M of P about knife-edge axis is given by:

$$M = \frac{1}{2}\rho g b y^2\left(a + d - \frac{y}{2} + \frac{y}{6}\right) \tag{6}$$

and then $$M = \frac{1}{2}\rho g b y^2\left(a + d - \frac{y}{3}\right) \tag{7}$$

Also M = gmL

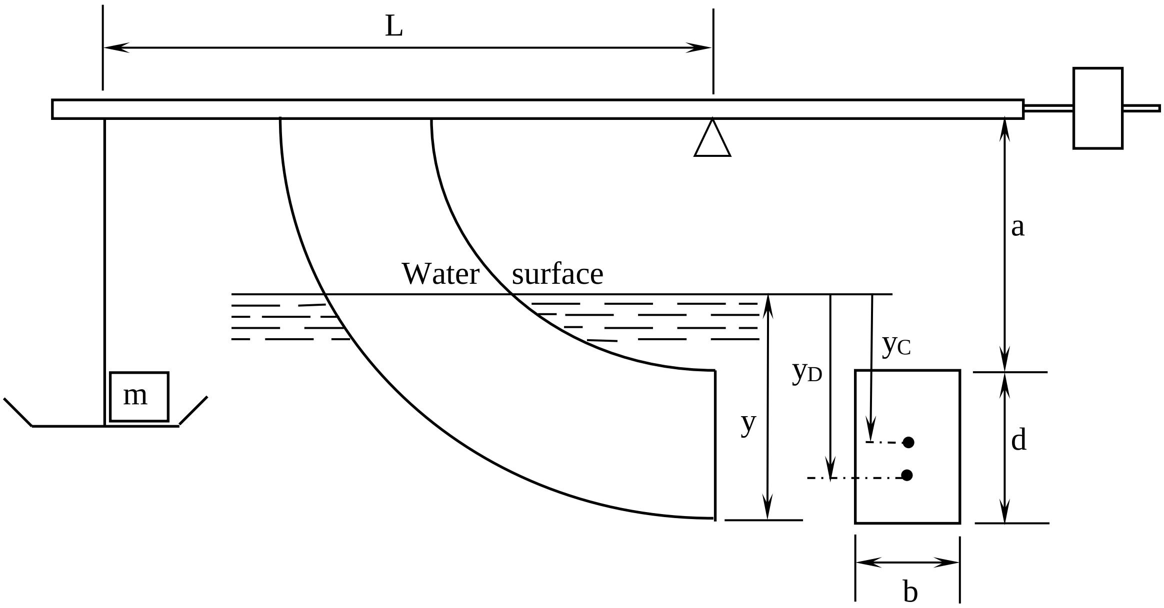
Where m = mass added to balance pan

L = distance from knife-edge axis to balance pan suspension rod axis

Thereby,

$$mL = \frac{1}{2}\rho b y^2\left(a + d - \frac{y}{3}\right) \tag{8}$$

- **Complete immersion**



$$h_C = y_C = y - \frac{d}{2} \text{ ; A = bd} \tag{9}$$

Hence $$P = \rho g\left(y - \frac{d}{2}\right)bd \tag{10}$$

$$y_D - y_C = \frac{bd^3/12}{bd(y - d/2)} = \frac{d^2}{12(y - d/2)} \tag{11}$$

Moment M of P about knife-edge axis is given by:

$$M = \rho g b d\left(y - \frac{d}{2}\right)\left(a + \frac{d}{2} + \frac{d^2}{12(y - d/2)}\right) \tag{12}$$

and thereby,

$$mL = \rho bd\left(y - \frac{d}{2}\right)\left(a + d + \frac{d^2}{12(y - d/2)}\right) \qquad (13)$$

IV. PROCEDURE

(a) Locate the torroid on the dowel pins and fasten to the balance arm by the central screw.

(b) Measure the dimensions a, b, and d, and the distance L from the knife – edge axis to the balance pan axis.

(c) Position the perspex tank on work surface and locate the balance arm on the knife edges.

(d) Attach a length of hose to the drain cock and direct the other end of hose to the sink. Attach a length of hose to tap V_3 and place the free end in the triangular aperture on the top of the perspex tank.

Level the tank, using the adjustable feet in conjunction with the spirit level.

(e) Adjust the counter - balance weigh until the balance arm is horizontal. This is indicated on a gate adjacent to the balance arm.

(f)Fill water to the perspex tank until the water is level with the bottom edge of the torroid.

(g) Place a mass on the balance pan and fill water to the tank until the balance arm is horizontal. Note the water level on the scale.

Fine adjustment of the water level may be achieved by over – filling and slowly draining, using the drain cock.

(h) Repeat the procedure under section (g) for different masses : 5 masses for water levels y > d (complete immersion) and 5 masses for y < d (partial immersion)

(i) Repeat readings for reducing masses on the balance pan.

All record data can be arranged as shown in table 1 and 2

Table 1.

a(cm)	b(cm)	d(cm)	L (cm)

Table. 2

Case	m (g)	y (cm)
Complete immersion y < d		
Patital immersion Y > d		

V. REPORT

- For y< d *(partial immersion)*

Tabulate $\frac{m}{y^2}$ and plot $\frac{m}{y^2}$ against y

From (8) $\frac{m}{y^2} = \frac{\rho b}{2L}\left(a + d - \frac{y}{3}\right)$

It is found that the slope of this graph should be $-\frac{\rho b}{6L}$

And the intercept should be $\frac{\rho b(a+d)}{2L}$

Comparision between the experimantal results and theory

- For y> d *(complete immersion)*

Tabulate $\bar{y} = \left(y - \frac{d}{2}\right)$, $\frac{m}{\bar{y}}$ and $\frac{1}{\bar{y}}$

Plot $\frac{m}{\bar{y}}$ against $\frac{1}{\bar{y}}$

From (13), it is found that the slope of this graph should be $\rho bd^3/(12L)$

And the intercept should be $\frac{\rho bd}{L}\left(a + \frac{d}{2}\right)$

Comparision between the experimantal results and theory

V. CONCLUSIONS

Give reasons for the discrepancies, if any, between the measured and predicted values of the above expressions for the graph parameters.

Experiment 4: Osborne Reynolds

1- Objective:

The objective of this experimental setup is the:

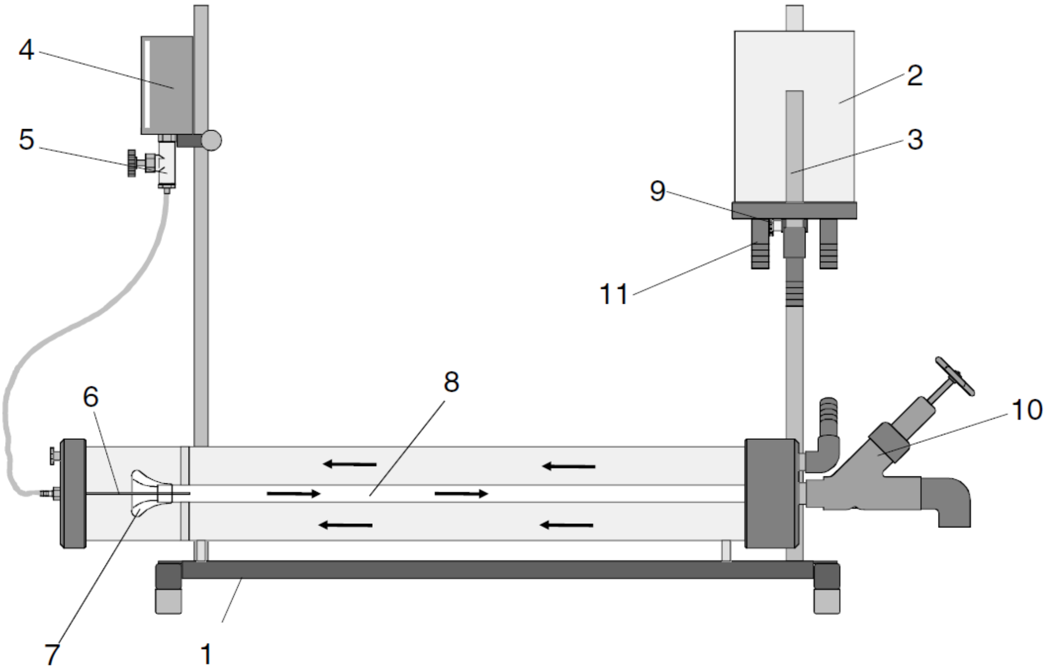
- visualization of laminar flow
- visualization of the transition zone
- visualization of turbulent flow
- determination of the critical Reynolds number

2- Principle of test

a low flow rate laminar flow is established. For this purpose open the drain cock a little. Blue ink is used to visualize the flow. A fine blue flow line can be generated using the metering cock, which shows the laminar flow. At a high flow rate turbulent flow occurs For this purpose open the drain cock further. The flow line is broken up by the turbulent flow.

3- Osborne Reynolds Apparatus

The unit is intended for the investigation and demonstration of the Osborne Reynolds experiments. The experimental setup facilitates the demonstration of laminar and turbulent flow. The flow is made visible with an ink trace in a transparent section of tube.



The unit essentially comprises:

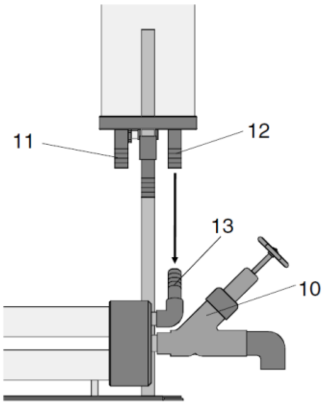
- **Base plate** [1].
- **Water supply tank** [2] with **height adjustment** [9] and connection for **water supply** [11].
- **Overflow section** [3] for the generation of a constant pressure head in the supply tank.
- **Aluminium tank** [4] for ink with **metering cock** [5] and **brass injection nozzle** [6].
- **Experiment tube** [8] made of Plexiglass with streamlined **inlet section** [7].
- **Drain cock** [10] for adjusting the flow rate in the experiment tube.

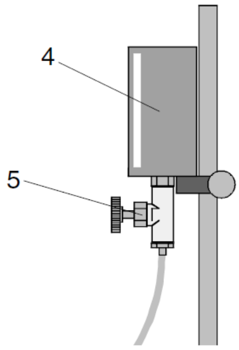
To visualise the flow we recommend blue ink, which is carefully introduced into the flowing water

4- Preparation and Setting Up the Unit

The following must be performed to set up and prepare for the experiment:

- Place the unit on a bench or on the **HM150**. If you are not using the **HM150**, a permanent water drain should be available near the unit.
- Connect the water drain hose to the drain cock [10] or place the unit over a drain. If you are using the **HM150**, you can set up the unit such that the water is drained directly into the reservoir in the **HM150**. Water with ink should not be allowed to drain into the **HM150** reservoir.
- Connect the outlet [12] on the supply tank to the inlet [13] on the test section by means of a hose.
- Connect a water supply to the inlet [11] on the supply tank using a hose.



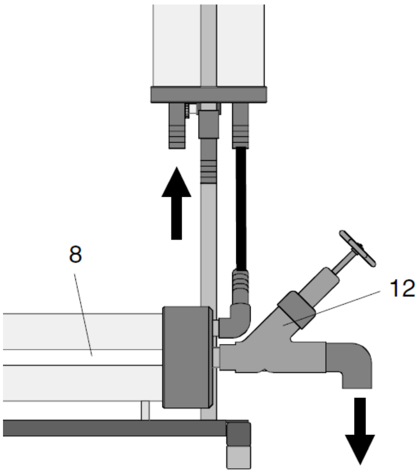


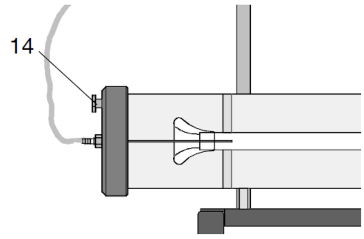
- Fill the aluminium tank [4] with ink. The ball cock [5] underneath the tank must be closed.

5- Performing the Experiment

- Close the drain cock [12].
- Switch on the water supply. On the HM150, the pump. Carefully open the
ball cock above the pump or the water cock on the laboratory supply.
- Adjust the cock such that a constant water level is established in the supply tank.

- After a certain amount of time, the experiment tube [8] fills.
- The remaining air can be removed from the experiment tube by undoing the bleed screw [14].





The experiment can now begin. Open the drain cock a little such that a low flow rate is produced in the experiment tube. It is best to dispose of the dyed water down a drain.

6- Calculation:

The change from laminar flow to turbulent flow
occurs at:

Recr ≈ 2300

Relam. ≤ 2300 signifies laminar flow

Retur. ≥ 2300 signifies turbulent flow

The Reynolds number is calculated from

$R_e = \frac{W.d}{\nu}$ with

d= Inside diameter of the pipe section [m]

w= Flow speed [m/s]

v= Viscosity of the medium [m2/s],

water: v = 10-6 [m2/s]

The flow speed can be determined from the volumetric flow rate; this is determined using a measuring tank and a stopwatch.

$$W = \frac{\dot{V}}{\mathrm{A}}$$

$$A = \frac{\pi . d^2}{4}$$

Pipe diameter d = 16mm = 0.016m

$\dot{V}$= Volumetric flow rate

A= Cross-sectional area of the pipe

The figure below shows the three flow conditions:

- Laminar flow
- Transition laminar / turbulent flow
- Turbulent flow

7- Technical Data

Supply Tank: 2.0 litres

Experiment Tube:

Inside Diameter: 16 mm

Length: 700 mm

Ink Tank: 270 ml

Experiment 5: Impact of Jet

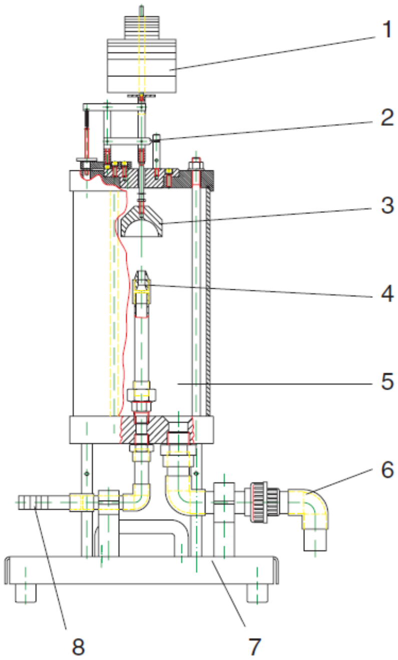
1- Objective:

Determine the jet impact forces from the principle of linear momentum

2- Principle of test

The impact forces of the water jet are set via the flow rate. Water is supplied either from the HM150 basic flow module or by way of the laboratory mains. The HM150 enables a closed water circuit to be constructed.

3- Unit Description



The unit essentially consists of:

- Base Plate [7]
- Inlet connection [8]
- Drain connection [6]
- Perspex vessel [5]
- Nozzle [4]
- Deflector [3]
- Lever mechanism [2]
- Loading weights [1]

Various deflectors can be fitted at position [3].

- Plate
- Hemissphere
- Slope
- Cone

4- Preparing and Performing the Experiment

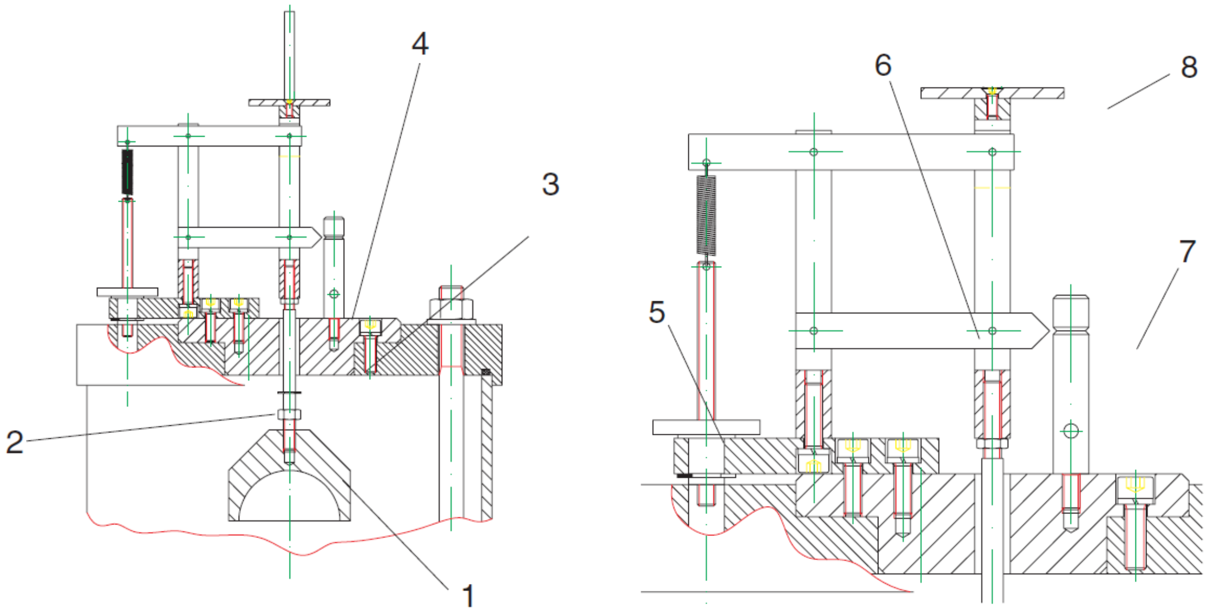
Performance of Experiment:

– Place the test set-up on the HM150 so that the drain routes the water into the channel.

– Fit connecting hose between HM150 and unit.

– Open HM150 drain.

– Assemble deflector [1], (Plate, Hemisphere, Slope or Cone). Loosen the 3 screws [3] on the cover [4] and remove cover together with lever mechanism. Fit appropriate deflector. Do not forget to tighten lock nut [2] on rod. Screw cover back onto vessel.



– Use adjusting screw [5] to set pointer to zero (zero notch [7]). When doing so, do not place any loading weights on measurement system [8].

– Apply desired loading weight [8] 0.2N; 0.3N; 1N; 2N; 5N or combinations there of.

– Close main HM150 cock.

– Switch on HM150 pump.

– Carefully open main cock until pointer is on zero again.

– Close HM150 drain cock.

– Determine volumetric flow. This involves recording time t required to fill up the volumetric tank of the HM150 from 20 to 30 litres.

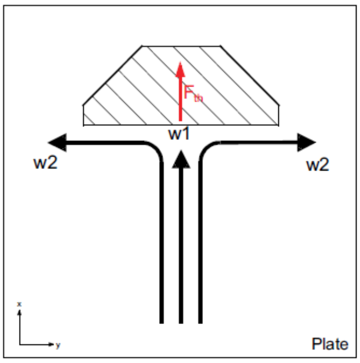
– Add loading weights and note down time t for 10 litres.

– Switch off pump, open drain.

5- Calculation of Theoretical Jet Force

The theoretical jet force is calculated from the principle of linear momentum

5.1 For Plate

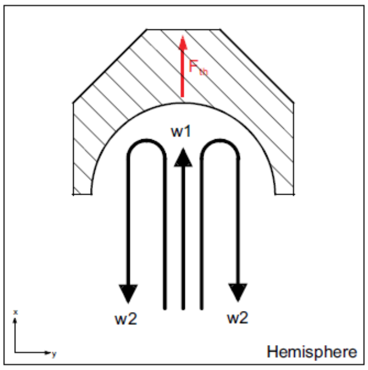


$$F_{th} = V \cdot \rho \cdot (w_1 - w_2)$$

if $w_2 = 0$ then

$$F_{th} = \dot{V} \cdot \rho \cdot w_1$$

5.2 For Hemisphere

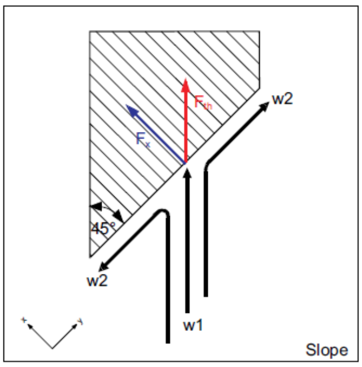


$$F_{th} = \dot{V} \cdot \rho \cdot (w_1 - w_2)$$

if $w_2 = -w_1$ then

$$F_{th} = 2 \cdot \dot{V} \cdot \rho \cdot w_1$$

5.3 For Slope



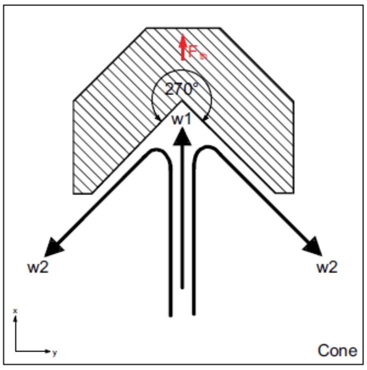
$$F_x = \dot{V} \cdot \rho \cdot w_1 \cdot \cos\alpha$$

$$F_{th} = F_x \cdot \cos\alpha \qquad \textit{with} \quad \alpha = 45^\circ$$

$$F_{th} = \dot{V} \cdot \rho \cdot w_1 \cdot \cos^2\alpha$$

Attention!
Please note direction of coordinate axis!

5.4 For Cone



$$F_{th} = \dot{V} \cdot \rho \cdot (w_1 - w_{2x})$$

$$w_2 = - w_1 \cdot \cos\alpha \qquad \textit{with} \;\; \alpha = 45^\circ$$

$$w_{2x} = w_2 \cdot \cos\alpha$$

$$F_{th} = \dot{V} \cdot \rho \cdot w_1 \cdot (1 + \cos^2 \alpha)$$

6. Results

The velocity w_1 of the jet from the nozzle is calculated from the volumetric flow and the cross-sectional area A_D of the nozzle.

$$\boxed{w_1 = \frac{4 \cdot \dot{V}}{\pi \cdot d^2} = \frac{\dot{V}}{A_D}}$$

$$\text{where} \qquad A_D = \frac{\pi \cdot d^2}{4}$$

Nozzle diameter d = 10mm = 0,01m

Flow rate V in ltr/s	**velocity w_1 in m/s**	**calculated Force F_{th} in N**	**measured Force F in N**

Comparison of Theoretical and Measured Force

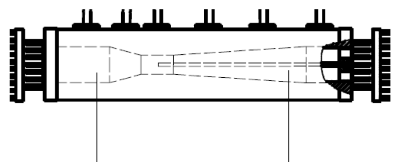
Calculation of the jet impact forces from the principle of linear momentum yields a good level of coincidence with the measured Values:

Example Value : 1 N	**calculated Force Fth in N**	**mesaured Force F in N**
Plate		
Hemisphere		
Slope		
Cone		

Experiment 6: Bernoulli's Theorem Demonstration

1- Objective:
The measured values are to be compared to Bernoulli's equation.

2- Theory:
Bernoulli's equation for constant head h:

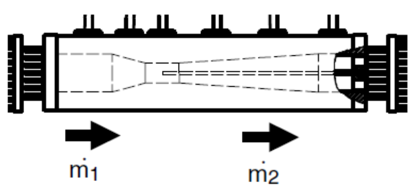


$$\frac{P_1}{\rho} + \frac{W_1{}^2}{2} = \frac{P_2}{\rho} + \frac{W_2{}^2}{2} = const$$

Allowance for friction losses and conversion of the pressures P_1 and P_2 into static pressure heads h_1 and h_2 yields:

$$h_1 + \frac{W_1{}^2}{2g} = h_2 + \frac{W_2{}^2}{2g} + h_v$$

P_1: Pressure at cross-section A_1
h_1: Pressure head at cross-section A_1
w_1: Flow velocity at cross-section A_1
P_2: Pressure at cross-section A_2
h_2: Pressure head at cross-section A_2
w_2: Flow velocity at cross-section A_2
ρ: Density of medium = constant for incompressible fluids such as water
h_v Pressure loss head
The mass flow is constant in closed systems.



$$\dot{m}_1 = \dot{m}_2$$

Given

$$\dot{m} = \dot{V}.\rho$$
$$\dot{V}_1.\rho = \dot{V}_2.\rho$$
$$\dot{V}_1 = \dot{V}_2$$

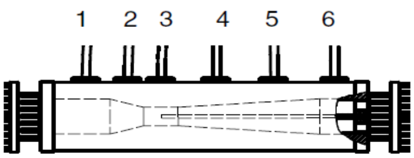
Given

$$\dot{V} = A.w$$
$$A_1.w_1 = A_2.w_2 = \dot{V} = const$$

3- Velocity profile in venturi tube

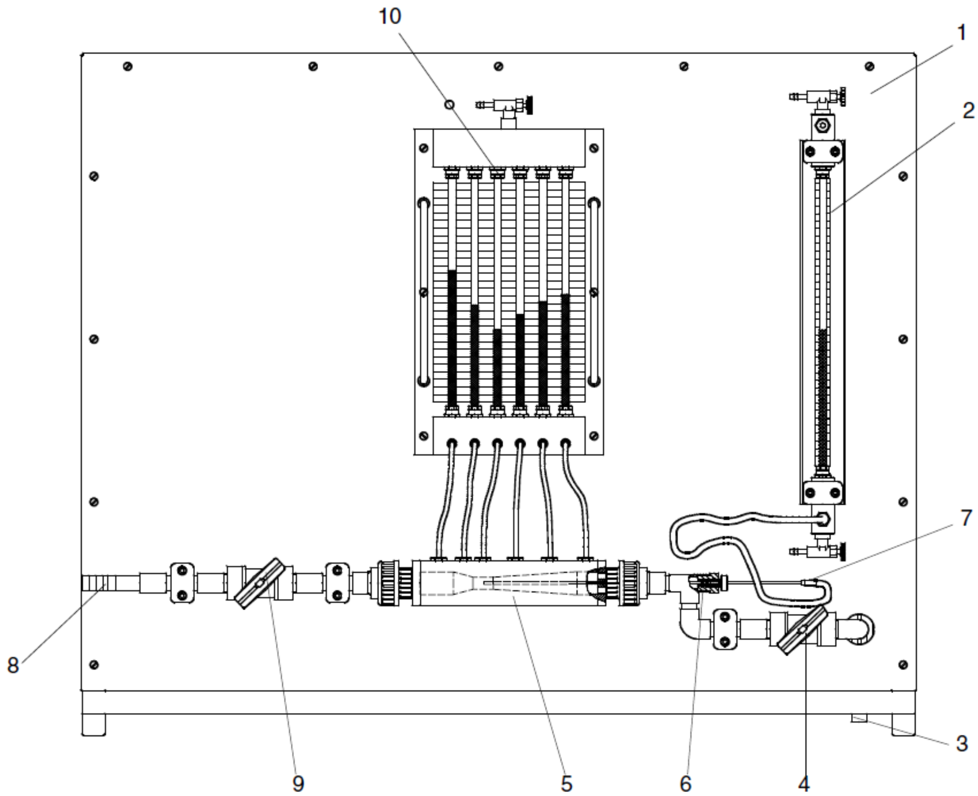
The venturi tube used has 6 measurement points. The table below shows the standardized reference velocity w. This parameter is derived from the geometry of the venturi tube.

$$\overline{w}_i = \frac{A_1}{A_i}$$



Point i	Di [mm]	A $[m^2 \cdot 10^{-4}]$	reference velocity $\overline{w}$
1	28,4	6,33	1
2	22,5	3,97	1,59
3	14,0	1,54	4,11
4	17,2	2,32	2,72
5	24,2	4,60	1,37
6	28,4	6,33	1

4- Bernoulli's Theorem Demonstration Apparatus



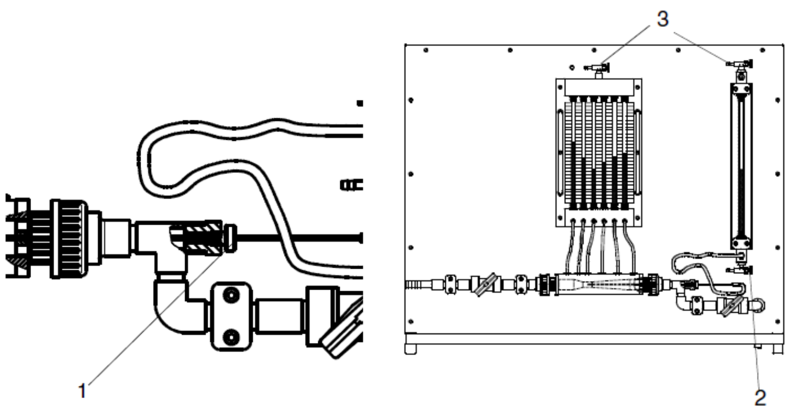
1 Assembly board 6 measurement points 6 Compression gland

2 Single water pressure gauge
3 Discharge pipe
4 Outlet ball cock
5 Venturi tube with

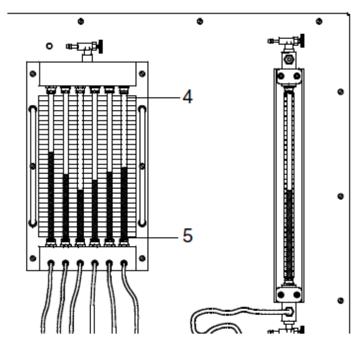
7 Probe for measuring overall pressure (can be moved axially)
8 Hose connection, water supply
9 Ball cock at water inlet
10 6-fold water pressure gauge (pressure distribution in venturi tube)

5- Experiment

- Arrange the experimentation set-up on the HM150 such that the discharge routes the water into the channel
- Make hose connection between HM150 and unit
- Open discharge of HM150
- Set cap nut [1] of probe compression gland such that slight resistance is felt on moving probe

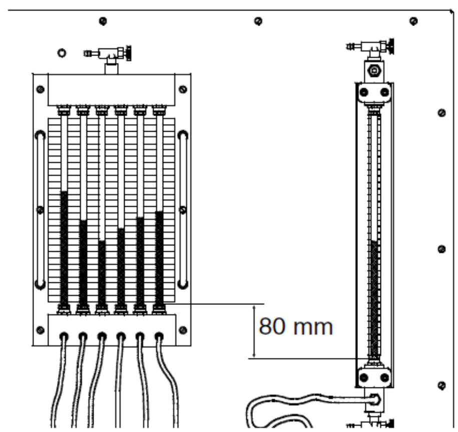


- Open inlet and outlet ball cock
- Close drain valve [2] at bottom of single water pressure gauge
- Switch on pump and slowly open main cock of HM150
- Open vent valves [3] on water pressure gauges
- Carefully close outlet cock until pressure gauges are flushed
- By simultaneously setting inlet and outlet cock, regulate water level in pressure gauges such that neither upper nor lower range limit [4,5] is overshot or undershot



- Record pressures at all measurement points. Then move overall pressure probe to corresponding measurement level and note down overall pressure
- Determine volumetric flow rate. To do so, use stopwatch to establish time t required for raising the level in the volumetric tank of the HM150 from 20 to 30 litres

For taking pressure measurements, the volumetric tank of the HM150 must be empty and the outlet cock open, as otherwise the delivery head of the pump will change as the water level in the volumetric tank increases.
This results in fluctuating pressure conditions. A constant pump delivery pressure is important with low flow rates to prevent biasing of the measurement results.
The zero of the single pressure gauge is 80 mm below that of the 6-fold pressure gauge. Allowance is to be made for this fact when reading the pressure level and performing calculations.



Both ball cocks must be reset whenever the flow changes to ensure that the measured pressures are within the display ranges.

6- Calculation of dynamic pressure head:

$h_{dyn.} = h_{tot.} - 80mm - h_{stat.}$

80 mm must be subtracted, as there is a zero-point difference of 80 mm between the pressure gauges. The velocity wmeas was calculated from the dynamic Pressure

$$w = \sqrt{2.g.h_{dyn}}$$

The following values were determined for various flow rates:

i	h_1	h_2	h_3	h_4	h_5	h_6	t(s) for 10L	$\dot{V}$ (m^3/s)
h_{stat}								
h_{tot}								
h_{dyn}								

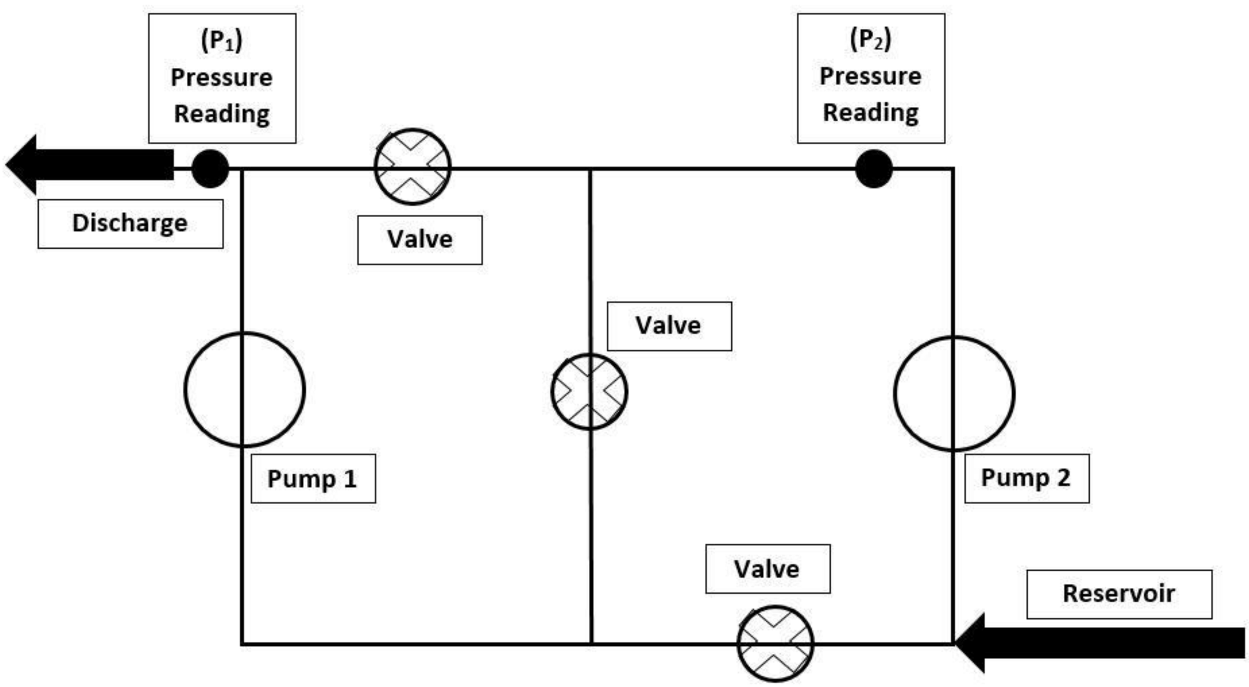
w_{mes}								
w_{cal}								
h_{stat}								
h_{tot}								
h_{dyn}								
w_{mes}								
w_{cal}								
h_{stat}								
h_{tot}								
h_{dyn}								
w_{mes}								
w_{cal}								

Experiment 7: Pumps in Series & Pumps in Parallel

BACKGROUND

Pumps are used to transfer fluid in a system, either at the same elevation or to a new height. The needed flow rate depends on the height to which the fluid is pumped. Each pump has a head-discharge relationship that is inversely proportional (i.e., if a higher flow rate is needed, then less head or pressure will be produced by the pump, and vice versa). This head-discharge relationship, also known as the pump characteristic curve, is provided by the pump manufacturer.

In civil engineering applications, a single pump often cannot deliver the flow rate or head necessary for a particular system. However, two pumps (or typically more in practice) can be combined in series to increase the height to which the fluid can be pumped at a given flow rate, or combined in parallel to increase the flow rate associated with a given value of head. The H32 pumping apparatus employed in this lab demonstrates how the combined pump characteristic curve (whether in series or parallel) compares with that of the single pump. In theory, if two pumps are combined in series, the pumping system will produce twice the head for a given flow rate. Similarly, if two pumps are combined in parallel, the pumping system is expected to have twice the flow rate of single pump for a given head.



LAB OBJECTIVES

To develop pump characteristic curves for a single pump, two pumps in series, and two pumps in parallel by measuring head (h) and flow rate (Q) using the experimental apparatus.

To develop theoretical pump characteristic curves for pumps in series and pumps in parallel experimentally derived single pump characteristic curve.

To compare the experimental and theoretical pump characteristic curves for pumps in series and pumps in parallel.

EXPERIMENTAL PROCEDURE

1. Adjust the valves on the apparatus so that a SINGLE pump is active.
2. Use the valve downstream of the pump(s) to control discharge and the corresponding head. For a given head (pressure) reading, use the volume-time method to measure the flow rate. Measure the flow rate three times. Record the values in the appropriate table on the attached data sheet.
3. Measure the head (pressure) downstream of each pump. *Make sure that you record the pressure while the pipe is at the same elevation as it was when you measured the flow rate.* Record the values in the appropriate table on the attached data sheet.
4. Now adjust the valves on the apparatus such that there are two pumps in SERIES. The flow rate should remain constant. Record the head (pressure) at each gage in Table 1.
5. With the pumps in series, repeat Steps 2 and 3 for five different discharge/head readings, plus with zero flow (shutoff head).
6. Now adjust the valves on the apparatus such that there are two pumps in PARALLEL.
7. Copy the total head (pressure) readings from the SINGLE pump trial into Table 2 [$E_{p(single)}$].
8. Adjust the flow valve downstream of the pumps until the pressure (E_p) reading on the gages match (or are very close to) the values recorded in Step 7. *Again, make sure that you record the pressure while the pipe is at the same elevation as it was when you measured the flow rate.*
9. Now perform the volume-time method in order to determine the flow rate with the pumps in parallel. Record the information in Table 2.
10. Repeat Steps 8 and 9 for all of the pressure measurements, including with no flow.

RESULTS

Compare the experimental and theoretical pump characteristic curves for pumps in series and pumps in parallel. Comparisons should be made both graphically and in terms of the percentage error. Record measurements taken during lab in the tables on the attached data sheet. Type these results in a spreadsheet and include them in the report.

CALCULATIONS

Show sample calculations for one trial (i.e., for one flow rate/head reading) as outlined below. Note: sample calculations for each pumping system should be provided when alternative forms of a given equation are needed. Label variables and use units in your calculations.

Calculate flow rate using the volume-time method.

Calculate the total head (E_p) for each system based on your measured/experimental values.

For the pumps in SERIES, calculate the theoretical total head ($E_{p(th\text{-}single)}$) which is expected based on theory. Hint: Remember that the total head for pumps in series should be double that of the single pump at the same flow rate.

For the pumps in PARALLEL, calculate the flow expected in theory. Hint: Remember that the flow through pumps in parallel should be double what was recorded for a single pump given the same pressure (head).

Calculate percent error (theoretical versus experimental) in total head for pumps in series ($E_{p(th\text{-}series)}$ vs. $E_{p(exp\text{-}series)}$) and percent error in flow for pumps in parallel ($Q_{(th\text{-}parallel)}$ vs. $Q_{(exp\text{-}parallel)}$). [See Table 3]

Add a polynomial trend-line to each data set.

For ease of unit conversion: 1 bar = 100 kN/m^2, 1000 liters/sec = 1 m^3/sec.

GRAPHS

Create two graphs showing pump characteristic curves as follows:

Graph 1 - Pumps in Parallel

- Single pump line (reference pump A)
- Theoretical line for pumps in parallel ($E_{p(single)}$ vs. $Q_{(th\text{-}parallel)}$)
- Experimental line for pumps in parallel ($E_{p(exp\text{-}parallel)}$ vs. $Q_{(exp\text{-}parallel)}$)

Graph 2 - Pumps in Series

- Single pump line (reference pump A)
- Theoretical line for pumps in series ($E_{p(th\text{-}series)}$ vs. $Q_{avg(single)}$)
- Experimental line for pumps in series ($E_{p(exp\text{-}series)}$ vs. $Q_{avg(single)}$)

DISCUSSION

1. List possible causes for differences between your predicted values and experimental values of the pump characteristic curves for pumps in series or parallel.
2. Given the data for reference pump A (N = 1850 rpm) collected/derived in this lab, use similarity laws to predict the values of discharge and head for pumps rotating at 3000 rev/min. Provide a table with the predicted values of discharge and head for a single pump, pumps in parallel, and pumps in series rotating at 3000 rev/min. (Similarity laws are discussed in Section 4.2.1 of *Water Resources Engineering* by Wurbs & James.)

DATA SHEET

Table 1. *Single Pump & Pumps in Series Data*

				Single Pump				Theoretical Pump Curves		Pumps in SERIES
Trial	**Time (s)**	**Volume (L)**	**Q**	Q_{avg} (single)	$E_{p(1)}$	$E_{p(2)}$	$E_{p(single)} = E_{p(2)}$	$E_{p(th\text{-}series)} = 2^* E_{p(single)}$	$Q_{(th\text{-}parallel)} = 2^*Q_{avg}$	$E_{p(1)}$
0	NA	NA	0	0	--					
1					--					
2					--					
3					--					
4					--					

Table 2. *Pumps in Parallel Data*

Trial	$E_{p(single)}$ [see Table 1]	$E_{p(1)}$	$E_{p(2)}$	$E_{p(exp\text{-}parallel)} = (E_{p(1)} + E_{p(2)})/2$	Time (s)	Volume (L)	Q	$Q_{(exp-\ \ )}$ =
0					NA	NA	0	
1								
2								
3								
4								
5								

Table 3. *Percent Error: Theoretical vs. Experimental*

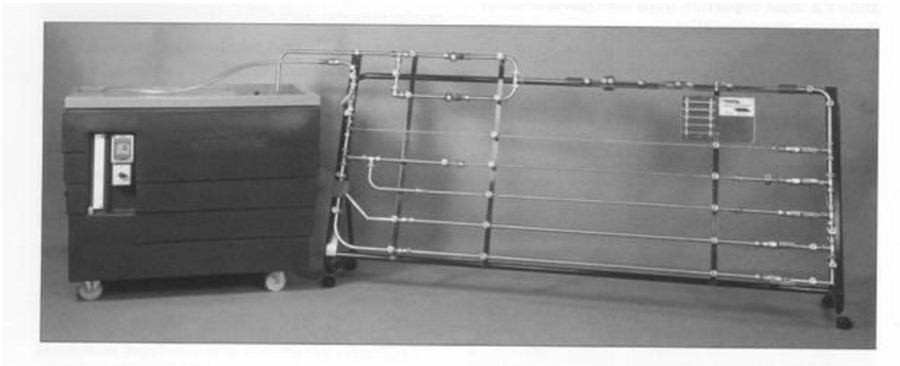
Trial	Pumps in Series			Pumps in Series	
	$E_{p(th\text{-}series)}$ [see Table 1]	$E_{p(exp\text{-}series)}$ [see Table 1]	% Error in E_p	$E_{p(th\text{-}parallel)}$ [see Table 2]	$E_{p(exp\text{-}parallel)}$ [see Table 2]
0					
1					
2					
3					
4					
5					

Experiment 8: Pipe friction loss in a smooth pipe

1- AIMS

To determine the relationship between head loss due to fluid friction and velocity for flow of water through smooth bore pipes and to confirm the head loss friction factor *f*.

2- APPARATUS



The Armfield C6-MKII-10 Fluid Friction Apparatus is designed to allow the detailed study of the fluid friction head losses which occur when an incompressible fluid flows through pipes, bends, valves and pipe flow metering devices.

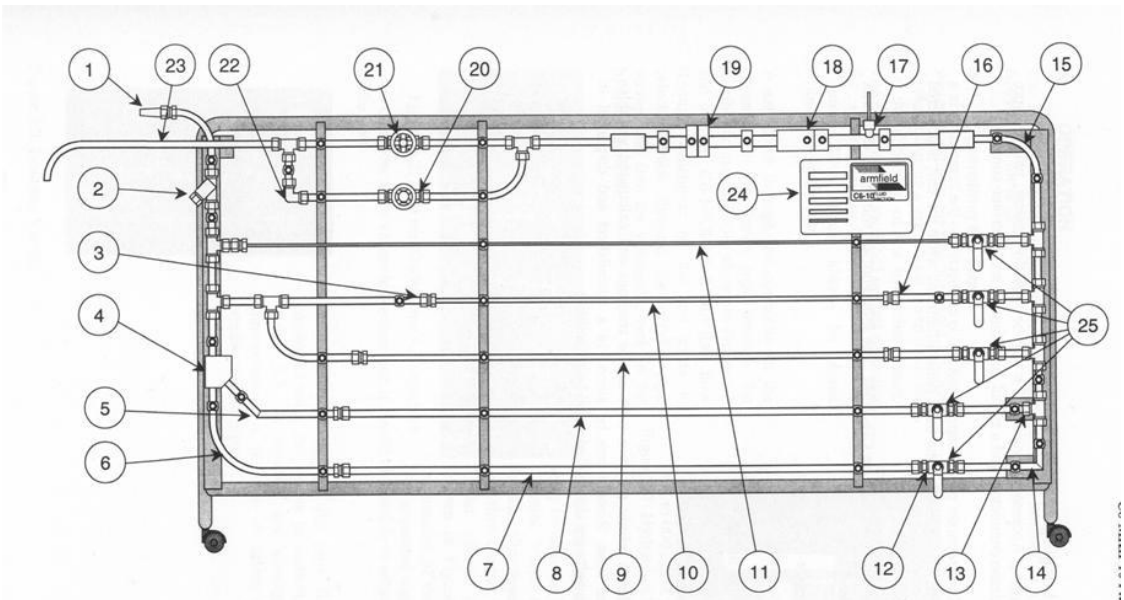


Figure 1: ARMFIELD C6-MKII-10 Fluid Friction Apparatus

The test pipes and fittings are mounted on a tubular frame carried on castors. Water is fed in from the hydraulics bench via the barbed connector (1), flows through the network of pipes and fittings, and is fed back into the volumetric tank via the exit tube (23). The pipes are arranged to provide facilities for testing the following:

- An in-line strainer (2)
- An artificially roughened pipe (7)
- Smooth bore pipes of 4 different diameters (8), (9), (10) and (11)
- A long radius 90° bend (6)
- A short radius 90° bend (15)
- A 45° "Y" (4)
- A 45° elbow (5)
- A 90° "T" (13)
- A 90° mitre (14)

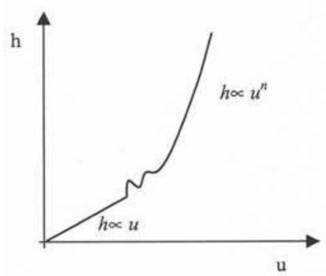
SPECIFICATIONS

Test Pipe Diameters:

1. 19.1mm x 17.2mm
2. 12.7mm x 10.9mm
3. 9.5mm x 7.7mm
4. 6.4mm x 4.5mm
5. 19.1mmx 15.2mm (artificially roughened) Distance between tapings: 1.00 m

- A 90° elbow (22)
- A sudden contraction (3)
- A sudden enlargement (16)
- A pipe section made of clear acrylic with a Pitot static tube (17)
- A Venturi meter made of clear acrylic (18)
- An orifice meter made of clear acrylic (19)
- A ball valve (12)
- A globe valve (20)
- A gate valve (21)

3- BASIC THEORETICAL BACKGROUND



Two types of flow may exist in a pipe.

1) Laminar flow at low velocities where $h \propto u$
2) Turbulent flow at higher velocities where $h \propto u^n$

Where *h* is the head loss due to friction and *u* is the fluid velocity:

For a circular pipe flowing full, the head loss due to friction may be calculated from the formula:

$$h = \frac{2fLu^2}{gd}$$

where: *L* is the length of the pipe between tapings, *d* is the internal diameter of the pipe,

u is the mean velocity of water through the pipe in m/s, g is the acceleration due to gravity
in m/s^2 and f is the pipe friction coefficient.

The mean velocity is obtained from

$$u = \frac{4Q}{\pi d^2}$$

here Q is the volumetric flowrate in m^3 /s

Reynolds' number, Re, is defined as:

$$u = \frac{\rho u d}{\mu}$$

where μ is the dynamic viscosity (1.15 x 10^{-3} Ns/m^2 at 15°C) and ρ is the density (999 kg/m^3 at 15°C).The value of f may be determined as a function of Re and the relative roughness $\varepsilon = e/d$ using a Moody diagram (provided at the end of the handout).
Equation (1) can be used to determine the theoretical head loss by reading the value of f for the pipe in the Moody diagram if you know Re and ε.
When h is measured experimentally, Eq. (1) can be rearranged to compute an experimental value for f.

$$f = \frac{hgd}{2Lu^2}$$

4- PROCEDURE

1. Prime the pipe network with water. Open and close the appropriate valves to obtain flow of water through the required test pipe.
2. Take readings at a number of different flow rates, altering the flow using the control valve on the apparatus, (ten readings is sufficient to produce a good head-flow curve).
3. Measure flow rates using the volumetric tank. For small flow rates use the measuring cylinder. Measure head loss between the tapings using the portable pressure meter or pressurized water manometer as appropriate.
4. Obtain readings on all four smooth test pipes if you have the time.

5- REPORT

1. All readings should be tabulated in the table provided at the end of the handout:
2. Plot a graph of h (experimental) versus u for each size of pipe. Identify the laminar, transition and turbulent zones on the graphs.
3. Confirm that the graph is a straight line for the zone of laminar flow $h \propto u$. Use the graph to determine the critical Reynolds' number for transition from laminar to turbulent flow.

4. Plot a graph of the experimental (direct reading) and calculated values of *h* (using Eq. 1 and the readings of *f* from the Moody diagram) versus Re for all pipe diameters in the same graph and make a comparison between the experimental and theoretical curves.

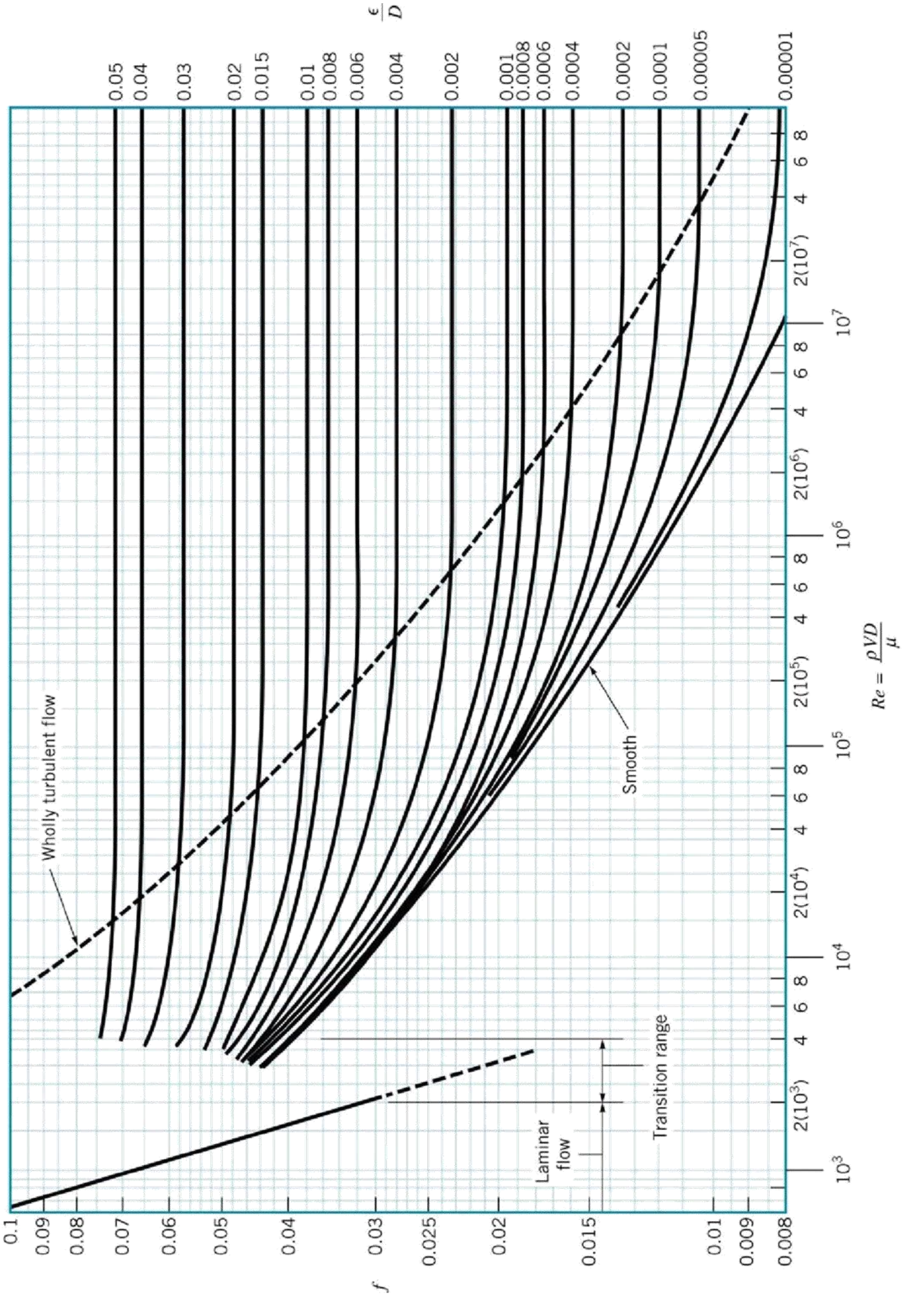
<u>Note:</u> be careful about the units so that you obtain *h* in m H_2O

Table of readings and results

Volume V [litres]	Time T [Secs]	Flow rate Q [m^3/s]	Pipe Diam. *d* [m]	Velocity *u* [m/s]	Reynolds Number Re	Measured Head Loss *h* [m H_2O]	Friction factor *f*	Calculated Head Loss *h* [m H_2O]
		$\frac{V \times 10^{-3}}{T}$		Eq.(2)	Eq.(3)	(h_C-h_D)	Moody Diagram	Eq.(1)

Table of readings and results

Volume V [litres]	Time T [Secs]	Flow rate Q [m^3/s]	Pipe Diam. *d* [m]	Velocity *u* [m/s]	Reynolds Number Re	Measured Head Loss *h* [m H_2O]	Friction factor *f*	Calculated Head Loss *h* [m H_2O]
		$\frac{V \times 10^{-3}}{T}$		Eq.(2)	Eq.(3)	(h_C-h_D)	Moody Diagram	Eq.(1)


Wholly turbulent flow
Laminar flow
Transition range
Smooth
$Re = \frac{\rho V D}{\mu}$
f
$\frac{\epsilon}{D}$
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.00005
0.00001
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.025
0.02
0.015
0.01
0.009
0.008
10^3
$2(10^3)$
10^4
$2(10^4)$
10^5
$2(10^5)$
10^6
$2(10^6)$
10^7
$2(10^7)$

<u>Experiment 10: Flow Through An Orifice</u>

1. GENERAL DESCRIPTION

This equipment allows measurement of contraction and velocity coefficients as well as discharge coefficient for an orifice discharge. It is to be used with HB100 Hydraulics Bench (separately supplied)

It consists of a removable clear acrylic cylinder with adjustable constant head. Water is admitted to the cylinder via a stainless steel wire mesh discharge head. An adjustable overflow allows various constant heads for the test. An orifice is fitted at the bottom of the cylinder flush with the base plate. A traverse assembly is provided below the cylinder. Attached to this assembly is a wire and a pitot tube. The wire is to measure the jet diameter hence the vena contracta diameter and the Pitot tube is to measure the jet velocity. The velocity head on Pitot tube and total head due to tank water level are indicated on manometer tubes. The apparatus rests on adjustable footings and a bull's eye level is provided.

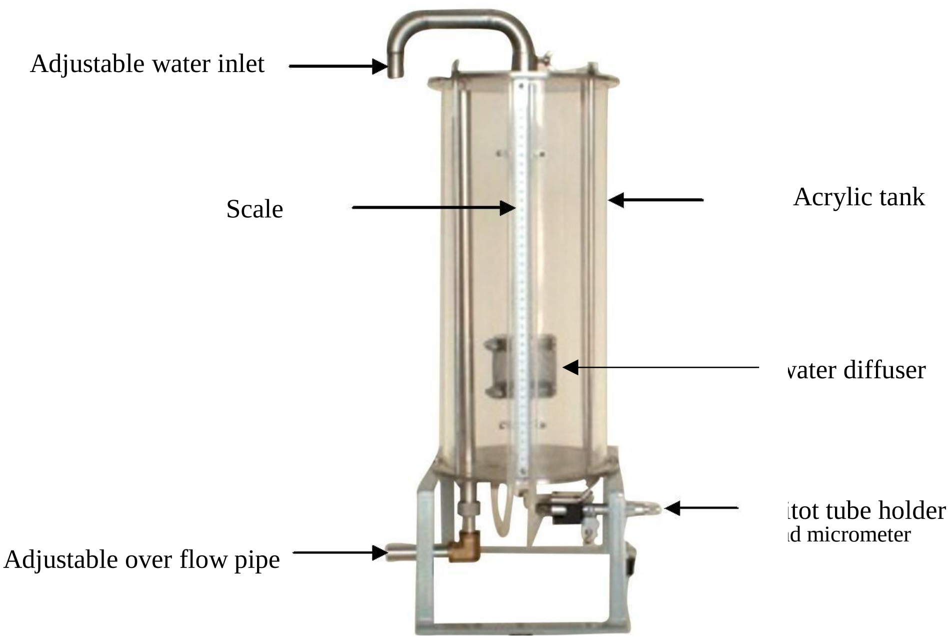


Figure 1 HB021 Flow through an orifice

2. TECHNICAL DATA

1.1	Cylinder diameter	:	150 mm
1.2	Standard orifice	:	13 mm diameter, sharp edge.
1.3	Maximum head	:	370 mm
1.4	Traverse travel	:	0.01 mm division.

3. THEORY

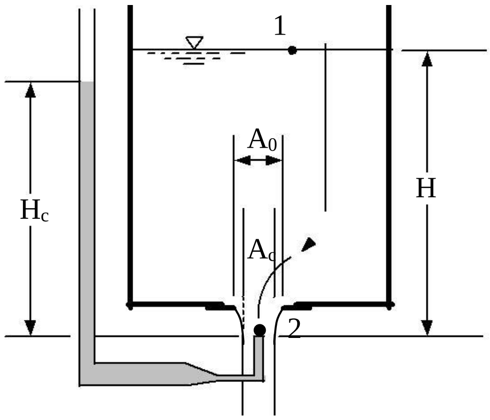


Figure 2-1 Discharge through the orifice

As the tank diameter is much larger than the orifice diameter the velocity of the water in the tank in the direction of the orifice flow is very low and can be neglected.

The velocity of water slowly increases as it approaches the orifice. The streamline of the flow is shown in Figure 2-1, from point 1 on the water surface of the tank to point 2 which is at the smallest area of the jet. The water jet will reduce its diameter after passing through the orifice. This is known as Vena Contracta.

Pitot head level can be adjusted to measure the velocity of the jet at the Vena Contracta. Apply Bernoulli's equation between point 1 and point 2 which gives us.

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+Z_2 \qquad \text{.................. (2.1)}$$

v = velocity, m/s
Z = elevation, m
γ = specific weight of water, N/m^3
g = acceleration due to gravity = 9.81, m/s^2

Subscript 1 and 2 refer to point 1 and point 2 respectively.

Since p_1 and p_2 are equal to the atmospheric pressure, the theoretical velocity of jet at Vena Contracta from equation (2.1) give us:

$$0+0+Z_1=0+\frac{V_2^2}{2g}+Z_2$$

$$V_{2,th}=\sqrt{2g(Z_1-Z_2}$$

$$V_{2,th}=\sqrt{2g}H \qquad \text{............. (2.2)}$$

The actual velocity $v_{2,act}$ of the jet at Vena Contracta can be measured directly by a Pitot tube. The velocity head from the Pitot tube is equal to the height H of water in the Pitot tube, therefore

$$V_{2,act}=\sqrt{2g}H_c \qquad \text{............. (2.3)}$$

The ratio of $v_{2,act}$ to $v_{2,th}$ is called Velocity Coefficient C_v of the orifice, then

$$C_v=\frac{V_{2,act}}{V_{2,th}}=\frac{\sqrt{2g}H_c}{\sqrt{2g}H}=\sqrt{\frac{H_c}{H}} \qquad \text{.............. (2.4)}$$

The ratio of the cross section area A_c of the jet at Vena Contracta to the cross-sectional area A_o of the orifice is called the Coefficient of Contraction, then

$$C_c = \frac{A_c}{A_0} = \frac{d_c^2}{d_0^2} = (\frac{d_c}{d_0})^2 \qquad \text{………..….. (2.5)}$$

Where d_o = diameter of orifice, m

A_o = cross sectional area of orifice, m^2; ($A = \pi d_o^2/4$)

d_c = diameter of jet at Vena Contracta, m

A_c = cross sectional area of jet at Vena Contracta, m^2; ($A = \pi d_c^2/4$)

Theoretical discharge through the orifice

Theoretical discharge through the orifice

$$Q_{th} = A_0 \times V_{2,th} = A_0 \times \sqrt{2g}H$$

Actual discharge through the orifice

$$Q_{act} = A_c \times V_{2,act} = A_c \times \sqrt{2g}H_c$$

The ratio of actual discharge of orifice to theoretical discharge is called the Coefficient of Discharge, C_d then:

$$C_d = \frac{Q_{act}}{Q_{th}} \frac{A_c \times V_{2,act}}{A_0 \times V_{2,th}}$$

$$C_d = C_c \times C_v \qquad \text{………….. (2.6)}$$

4. TEST PROCEDURES

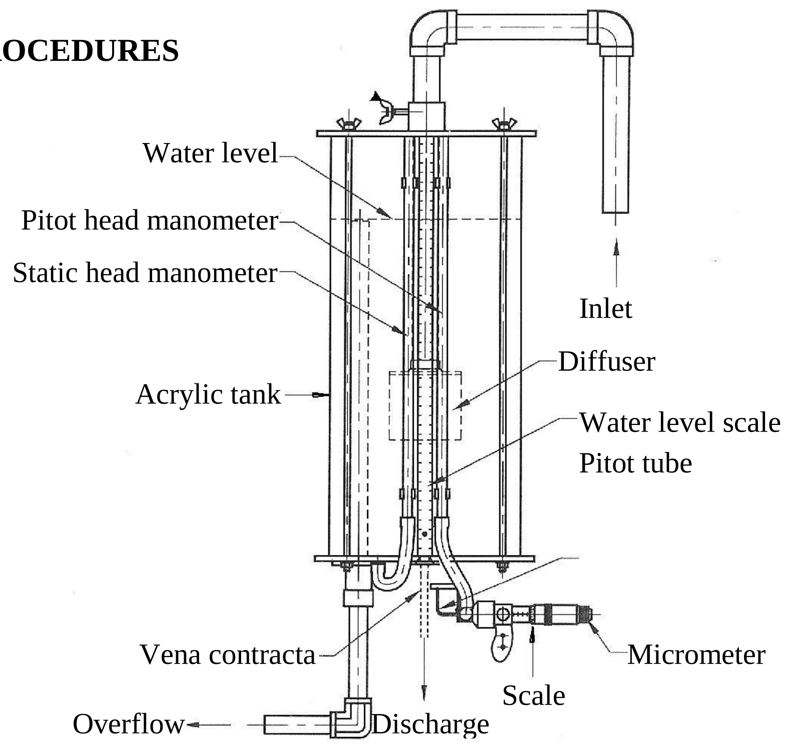


Figure 3 Schematic diagram of Flow Through an Orifice

The objective of this experiment is to determine C_v, C_c and C_d at the various heads "H".

3.1 Set the Hydraulics Bench to a level position as per the Hydraulics Bench instruction manual.

3.2 Connect the water supply line from the Hydraulics Bench to the inlet and outlet of the test apparatus.

3.3 Start the pump and slowly open the discharge valve to admit water to the tank until a small and steady over
flow is observed.

3.4 Record H and the flow rate by using the Hydraulics Bench measuring tank and stop watch.

3.5 Swing the micrometer so that the Pitot tube is inline with the jet and at a distance below the orifice approximately equal to the diameter of the orifice.

3.6 Slowly turn the micrometer knob until the wire starts touching the jet and record the micrometer reading. 3.7 Turn the micrometer knob further and record the Pitot tube reading H_c.

3.8 Turn the micrometer knob until the wire start leaving the jet and again record the micrometer reading. Diameter of the Vena Contracta is the difference between as per 3.6 and 3.8 reading.

3.9 Repeat steps 3.4 to 3.8 at the other overflow tube positions (different values of H).

DATA SHEET for HB021 FLOW THROUGH AN ORIFICE

Tested by…………..….……..……Date…………..……..….

Diameter of orifice =………..mm

Flow rate =…………………..l/s

Static head, H cm	Velocity head, H_c cm	Diameter at Vena Contracta, d_c mm	Coefficient of Contraction, C_c	Coefficient of Velocity, C_v	Coefficient of Discharge, C_d

OPEN CHANNEL HYDRAULICS

Experiment (1)
Roughness of Open Channel

I- Introduction:

An open channel is a waterway, canal or conduit in which a liquid flows with a free surface. Open channel flow describes the fluid motion in an open channel. In most applications, the liquid is water and the air above the flow is usually at rest and at standard atmospheric pressure.

In the absence of any other channel control, the flow is controlled only by friction with the bed and the sides of the channel. In this case, water flows with a uniform depth (normal depth) at which the weight component in the direction of the flow balances with the friction force induced by the flow resistance with the bed and sides. Many equations were developed to relate the bed roughness with the flow parameters in open channels. Among these equations is the manning equation which is widely used to relate the flow velocity and the cross sectional parameters with the manning coefficient (n) which is a function in the bed material roughness. Another less common equation is the Chezy equation where the bed roughness is being expressed by chezy coefficient (c).

II- Objectives:

The main objective of this experiment is to determine an average value of both manning (n) and chezy (c) coefficients for the Gunt laboratory flume (HM 162).

The sides of the flume are made of glass while the bed is made of steel. Changing the water depth changes the contribution of the sides in the computed average roughness while the bed contribution remains the same. It's required to compute an average value of (n) and (c) for different water depths and discharges.

III- Anticipated Results:

The students should be able to:

- Control and measure the bed slope, water depth, and discharge in the laboratory flume.
- Use both Manning and Chezy equations and get the manning and chezy coefficients knowing all the other flow parameters.
- Notice how the roughness coefficients are affected by the average water depth inside the flume.

IV- Experimental Setup and Tools used:

The students are going to use the Gunt flume setup in the eastern laboratory inside the Civil Engineering Department. The Flume is about 7m long with a rectangular cross section of 30 cm width and 70 cm maximum depth. The flume has a slope adjusting mechanism to adjust the bed slope ranging from 1:40 (positive slope) to 1:200 adverse slope. The tail water gate at the end of the flume can be used to control the water level inside the channel. A point gage can be used to measure the water depth at any section in the fume. The point gage can be moved both laterally (along the cross section) and longitudinally (with the flow). Water is pumped into the flume from a ground reservoir tank and then collected at the channel end back to the tank again. The pumping system is supplied with a gate valve to control the.

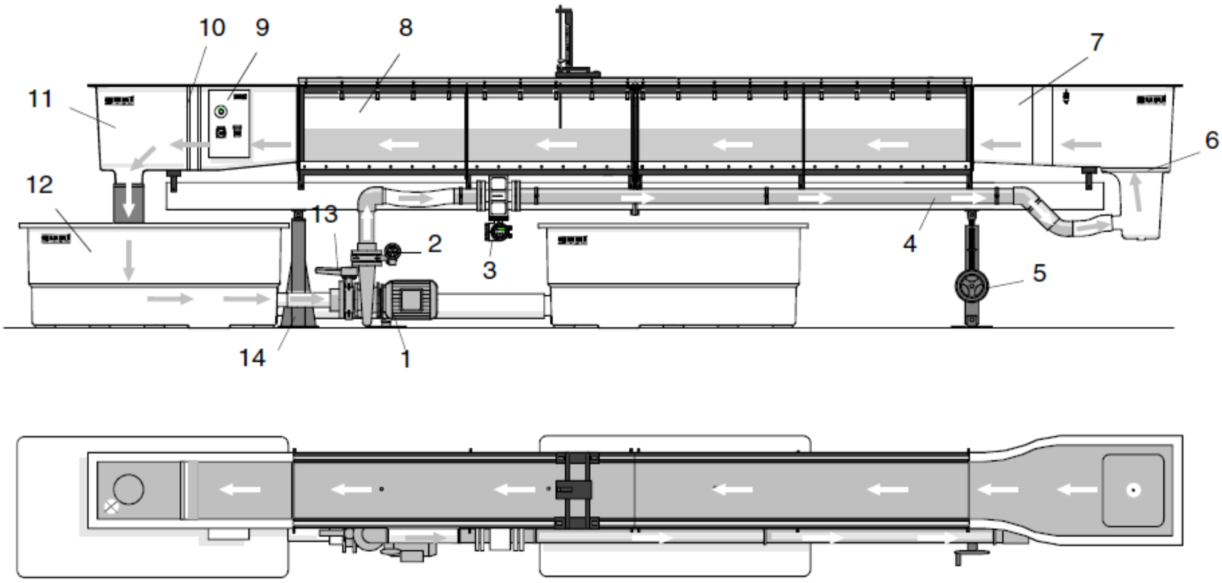


Fig. 2.1: Designation of the components; representation of the water cycle

1	Centrifugal pump
2	Shut-off valve w. gear system and handwheel to regulate flow rate
3	Flow-rate meter (magnetic-inductiv)
4	Pressure line
5	Incline adjustment facility with - trapezoidal spindles and handwheel
6	Flow rectifier
7	Intake element
8	Modular center element
9	Switch box
10	Movable overflow weir
11	Outflow element
12	Tank, modular
13	Shut-off valve
14	Fixed bearing

V- Experimental Procedure:

1. Adjust the slope and open the valve to get the suitable discharge and read the flow rate
2. Adjust the tail water gate to have an average water level inside the flume (low position). Do not use very low water levels.

3. Using the point gauge measure the water level (W.L) and the bed level (B.L.) at two sections 3 - 4 m apart. We should wait at least 15 minutes before measuring to reach the steady state.

4. For the same discharge set before, raise the tail water gate to increase the water level inside the flume (medium then high positions) and measure the W.L and B.L at the same sections. Care should be taken when raising the tail gate to avoid over flooding the flume.

5. Change the valve opening to get another different discharge in the flume and repeat the previous steps.

6. change the slope

VI- Equations Used:

$$Q = cR^{\frac{1}{2}} S_e^{\frac{1}{2}} A = \frac{1}{n} R^{\frac{2}{3}} S_e^{\frac{1}{2}} A$$

$y_1 = (W.L)_1 - (B.L.)_1, \qquad y_2 = (W.L)_2 - (B.L.)_2$

$$V_1 = \frac{Q}{by_1}, \qquad V_2 = \frac{Q}{by_2}$$

$$S_e = \frac{\left(y_1 + \frac{V_1^2}{2g}\right) - \left(y_2 + \frac{V_2^2}{2g}\right)}{L} + S_0$$

$$y_{avg} = \frac{y_1 + y_2}{2}$$

$$A = by_{avg},$$

$$p = b + 2y_{avg}$$

$$R = \frac{A}{p} = \frac{by_{avg}}{b + 2y_{avg}}$$

Where:

Q	= Flow rate (m^3/sec)
V	= Average flow velocity (m/s)
S_e	= Slope of total energy line (m/m)
n	= Manning coefficient
c	= Chezy coefficient
R	= Hydraulic Radius (m)
P	= Wetted perimeter (m)
A	= Cross sectional area (m^2)
W.L	= Water level (m)
B.L	= Bed Level (m)
y_1	= Water depth at section 1 (m)
y_2	= Water depth at section 2 (m)
y_{avg}	= Average water depth (m)

VII- Results:

1. Calculate the manning and chezy coefficients for all the previous runs.

2. Plot the variation in manning coefficient versus the water depth (tail gate position) for each flow rate on the same plot. Also plot the variations with chezy coefficient.

3. Do manning and chezy coefficients vary with water depth (at the same discharge)?

4. Do manning and chezy coefficients vary with discharge (at the same water depth)?

VIII- Suggested Datasheet Headings:

	Tail Gate Position	Section	W.L	B.L	y (m)	V (m/s)	S_e	y_{av} (m)	A (m^2)	P (m)	R (m)	c	n
Q_1	Low	1											
		2											
	Med	1											
		2											
	High	1											
		2											
Q_2	Low	1											
		2											
	Med	1											
		2											
	High	1											
		2											

Experiment (2)
Velocity Distribution

I- Introduction:

When a fluid flows past a solid boundary, the velocity at all points adjacent to the surface is zero (in case of no slip condition) and it increases as we move away from the boundary. In open channels, the measured velocity will always vary across the channel section due to friction along the boundaries. This velocity distribution is not ax-symmetric as in case of pipes due to the presence of the free surface. The point of maximum velocity is not at the surface (expected location of zero shear stress) but is found just below it. This is due to the presence of secondary currents circulating from the boundaries towards the section center and the resistance at the air/water interface. Also, when the velocity distribution across a channel cross section is known, we can simply find the flowing discharge. The above method of discharge measurement is known as the velocity distribution method, and is commonly used in natural or irregular cross sections.

II- Objective:

The objective of this experiment is to get the velocity distribution across the open channel section. The discharge can be calculated by averaging the velocity of each point along the area of its neighborhood and compare the calculated discharge with the discharge obtained from the orifice meter.

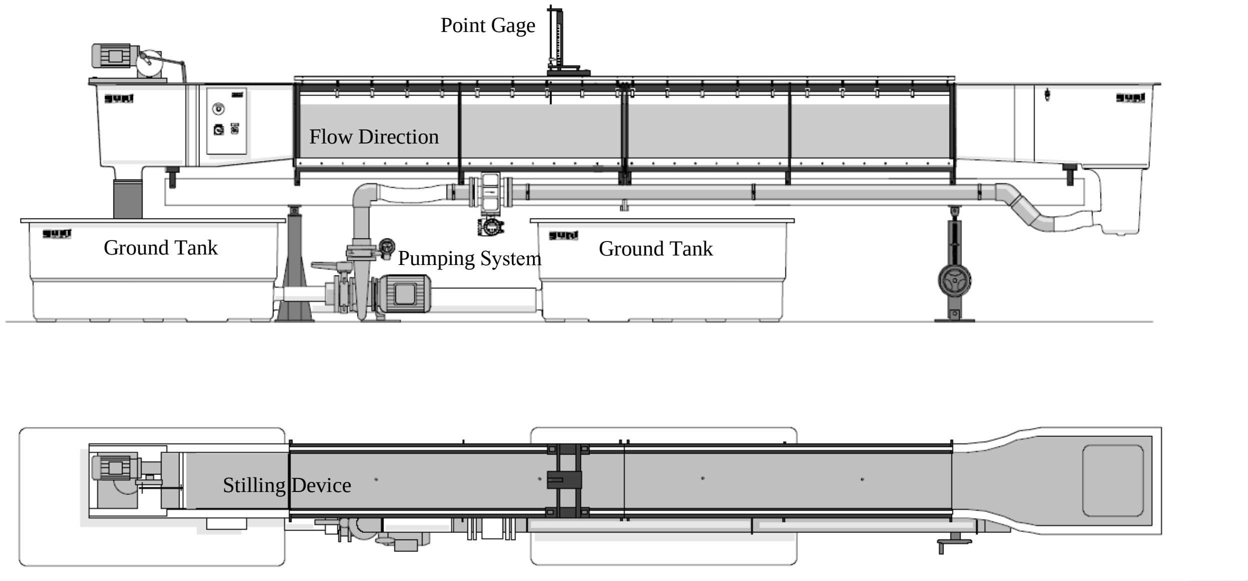
III- Anticipated Results:

The student should be able to:

1. Use the Pitot Tube to measure the velocity at a point
2. Integrate the measured velocity over the cross section area to get the flowing discharge and compare it with other measuring devices and find the percent error.
3. Draw velocity contours for the channel cross section and find the point of maximum velocity.

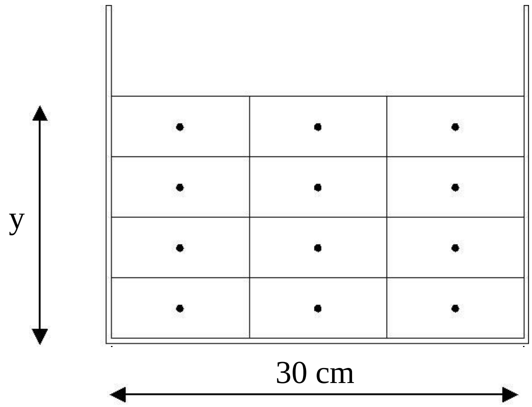
IV- Experimental Setup and Tools used:

same Gunt laboratory flume described in Experiment-1 will be used in this experiment. The magnetic-inductive flow rate sensor is installed in the pressure line to the intake element. This sensor type has the advantage that no pressure losses occur due to flow obstruction. It is set to a measuring range of 0-150 m3/h. The digital display alternately shows (every 10 sec.) the current flow rate in m3/h and the total flow rate in m^3.


Point Gage
Flow Direction
Ground Tank
Pumping System
Ground Tank
Stilling Device

V- Experiment Procedures:

1. Open the inlet valve to get a suitable discharge flowing into the flume. Measure the discharge using the orifice meter.
2. Adjust the tail water gate to have an average water depth of 35cm.
3. Wait to reach the steady state, and then measure the water depth at a section near the middle of the flume using the point gage. Place the current meter at the measured section.
4. Divide the section into 3 columns each column is divided into 4 strips. Note the area of each strip. Place the current meter's measuring disk in the middle of each strip and record the velocity from the screen after the 25 sec count is finished.



VI- results:

1. Plot on the same plot the vertical velocity distribution for each column.
2. Plot on the same plot the horizontal velocity distribution for each row.
3. Make and plot the velocity contours for the cross section (to scale).
4. Calculate the discharge in each strip (equals the velocity at the middle of the strip multiplied by the strip's area), and then add all strips together to get the total discharge flowing through the section.
5. Compare the calculated discharge using the current meter with the one measured with the orifice meter.

Experiment (3)
Discharge Measurement

I- Introduction:

The need for measuring the discharge in streams and rivers arises from the value of water to community. Accurate flow measurements are important for any water resources project.

The fixed relationship between depth and discharge that marks the critical flow makes this type of flow a convenient basis for discharge measurement. Based on that principle, various devices for flow measurement have been developed. In such devices, the critical depth is usually created either by constructing a hump on the channel bottom such as a weir or by producing a contraction in the cross section, such as a critical flow flume.

The fixed depth-discharge relationship in such devices depends on the physical nature of the structure. Once it's known, it's easy to measure the flowing discharge upon measuring the water depth at the defined section.

II- Objective:

The objective of this experiment is to measure the flow rate in an open channel using different open channel flow measuring structures.

III- Anticipated Results:

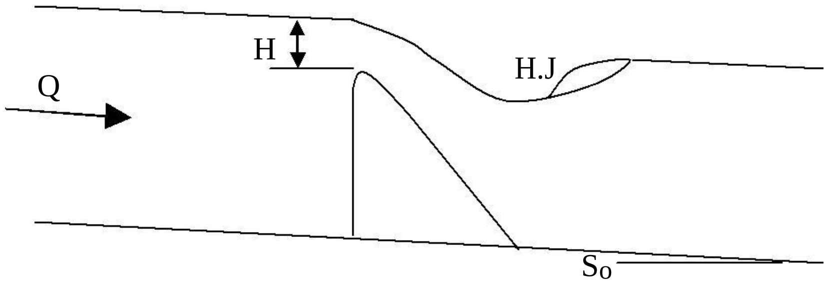
The students should be able to:

1. Setup critical flow in an open channel using a weir and a venturi flume.
2. Measure the discharge in the open channel using the given equations for each structure and compare it with the measured discharge from the orifice meter to get the percent error for various flow rates.
3. Find a better value for the coefficient of discharge in each equation to better fit the data.

A- Weir:

A structure used for measuring the discharge by making use of a combination of the phenomena of critical depth and hydraulic jump. The discharge is given by:

$$Q = 2.05\ B\ H^{1.5}$$



Experimental Procedure:

1. Adjust the bed slope of the flume to be (1/200).
2. Open the inlet valve to allow the flow to pass through the experimental flume and measure the discharge by the orifice meter.
3. Measure the head upstream the weir (H) and the weir length (B).
4. Calculate the discharge from: $Q = 2.05\ B\ H^{1.5}$
5. Compare the measured discharge with the calculated discharge.
6. Repeat for two other values of (Q) and find the constant in the weir equation.
7. Raise the tail water level gate till the weir becomes submerged and try to measure the discharge.

B- Flow over weirs

Introduction:

In open channel hydraulics, weirs are commonly used to either regulate or to measure the volumetric flow rate, they are of particular use in large scale situations such as irrigation schemes, canals and rivers. For small scale applications, weirs are often referred to as notches and invariably are sharp edged and manufactured from thin plate material.

Purpose:

To investigate the discharge-head characteristics of a rectangular and triangular weirs.

Apparatus:

Rectangular, triangular and trapezoidal notches (HM 162.30).
Hydraulic bench (HM 162).

HM 162.30 Set of Plate Weirs

Figure 1: Flow over weirs apparatus

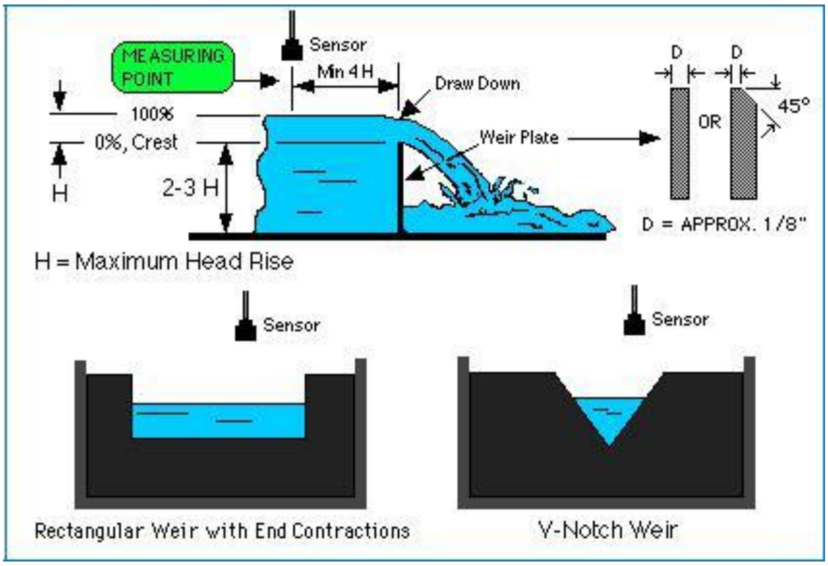


Figure 2: Rectangular and triangular notches

Equipment set up:

Place the flow stilling basket of glass spheres into the left end of the weir channel and attach the hose from the bench regulating valve to the inlet connection into the stilling basket.

Remove the five thumb nuts which hold the standard weir in place, remove the standard weir and replace it with the specific weir plate which is to be tested first. Ensure that the square edge of the weir faces upstream.

Flow measurement : The discharge from the weir may be measured using either the rotameter (if fitted) or by using the volumetric measuring tank and taking the time required to collect a quantity of water. The quantity should be chosen so that the time to collect the water is at least 120 seconds to obtain a sufficiently accurate result.

Measuring the weir datum : Fill the weir channel with water up to the weir plate crest level and use the hook gauge to measure the level of the water. This will be the zero or datum level for the weir.

Measuring the head : The surface of the water as it approaches the weir will fall, this is particularly noticeable at high rates of discharge caused by high heads. To obtain an accurate measure of the undisturbed water level above the crest of the weir it is necessary to place the hook gauge at a distance at least three times the head.

Theory:

1. Flow through a rectangular notch

A rectangular notch in a thin square edged weir plate installed in a weir channel

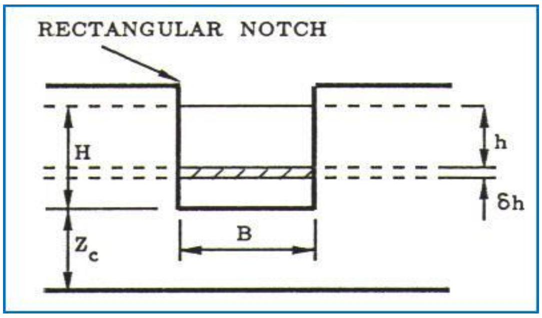


Figure 4: Rectangular notch

Consider the flow in an element of height at a depth below the surface. Assuming that the flow is everywhere normal to the plane of the weir and that the free surface remains horizontal up to the plane of the weir, then

In practice the flow through the notch will not be parallel and therefore will not be normal to the plane of the weir. The free surface is not horizontal and viscosity and surface tension will have an effect. There will be a considerable change in the shape of the nappe as it passes through the notch with curvature of the stream lines in both vertical and horizontal planes as indicated in figure 5, in particular the width of the nappe is reduced by the contractions at each end.

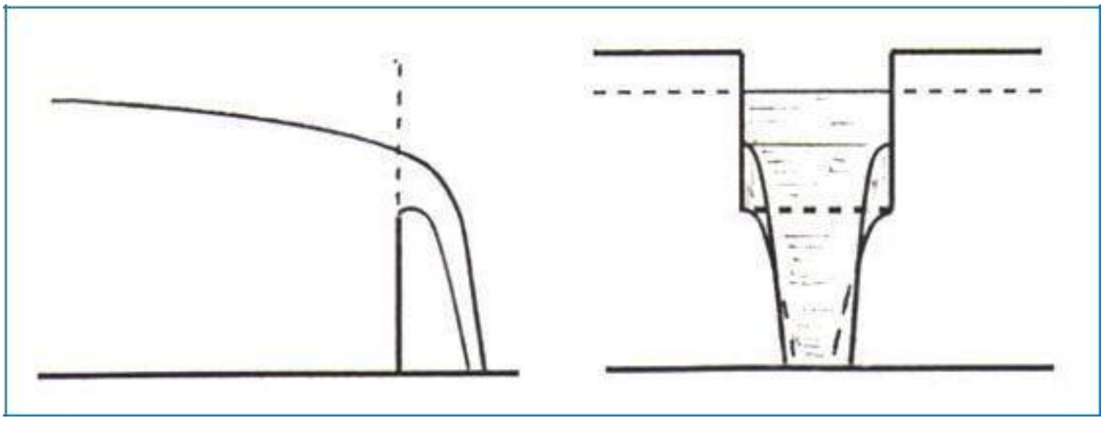


Figure 5: Shape of a nappe

The discharge from a rectangular notch will be considerably less, approximately 60% of the theoretical analysis due to these curvature effects. A coefficient of discharge is therefore introduced so that:

2. Flow through a triangular notch

A sharp edged triangular notch with an included angle of is shown in figure 6.

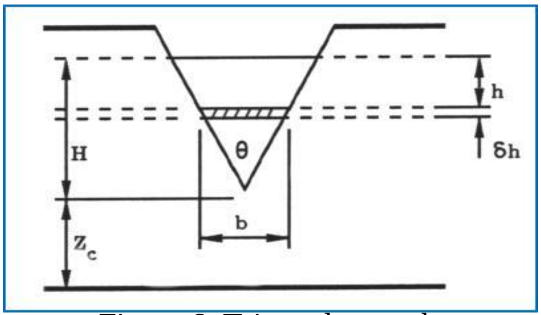


Figure 6: Triangular notch

Again consider an element of height at a depth

Breadth of element

Hence area of element

Velocity through element

Discharge through element

Integrating to obtain the total discharge between and Again, a coefficient of discharge has to be introduced.

The triangular notch has advantages over the rectangular notch since the shape of the nappe does not change with head so that the coefficient of discharge does not vary so much. A triangular notch can also accommodate a wide range of flow rates.

Procedures:

Start the pump and slowly open the bench regulating valve until the water level reaches the crest of the weir and measure the water level to determine the datum level.

Adjust the regulating valve to give the first required head level. Measure the flow rate Q. Observe the shape of the nappe.

Increase the flow by opening the regulating valve to set up heads above the datum level in steps of approximately 10mm until the regulating valve is fully open. At each condition read the flow rate and observe the shape of the nappe.

Close the regulating valve, stop the pump and then replace the weir with the next weir to be tested. Repeat the test procedure.

Results:

Record the results on a copy of the results sheet. Record any observations of the shape and type of nappe paying particular attention to whether the nappe was clinging or sprung clear, and of the end contraction and general change in shape.

2. Plot a graph of against for each weir. Measure the slopes and the intercepts. Calculate the coefficient of discharge from the intercept and confirm that the slope is approximately 2.5 for the rectangular notch and 1.5 for the triangular notch.