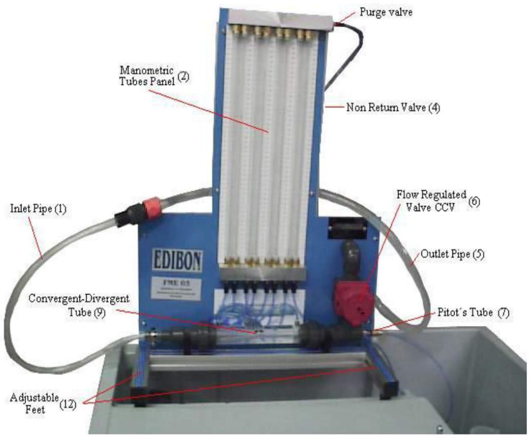
University of Misan

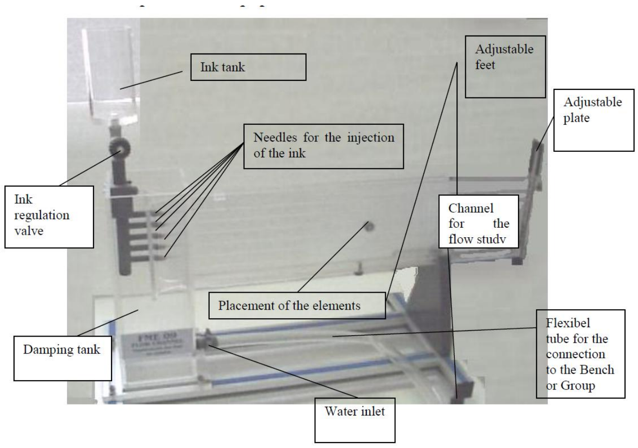
Engineering College

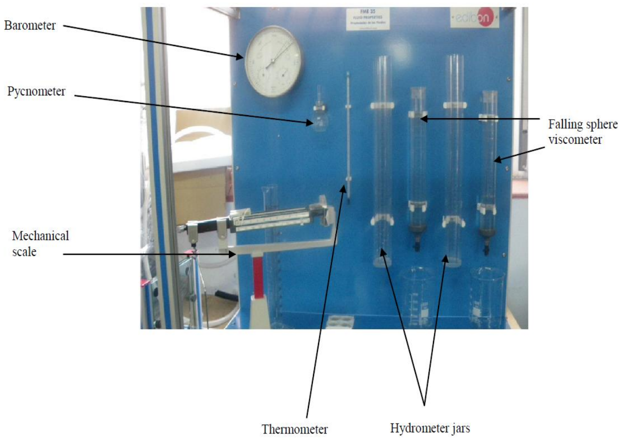
Fluid mechanics laboratory

Edited by

Assist. Prof. Dr. Ahmed Kadhim Alshara







Preface

This manual deals with experiments of fluid mechanics science, which studying in the engineering colleges in the engineering branches such as Petroleum engineering, Civil engineering, Mechanical engineering and Chemical engineering. The experiment No. one measures the fluid properties such as density, viscosity, capillarity tubes and Archimedes principles. In the experiment two, weights are used to calibrate Bourdon pressure gage. The types of manometers such as U-tube, piezometric tube and inclined manometer are presented in the experiment No. three. The Visualization of the flow in Channels over different bodies is studied in experiment No. four. The experiment No. five demonstration Pitot static tube that flow speed is proportional to the pressure difference between total pressure and static pressure. Proof of Bernoulli's theorem and determination of the exact section in the Venturi's tube are presented in experiment No. six. Reynolds number demonstration and type of flow (laminar or turbulent) are studied in experiment No. seven. The experiment No. eight studies three types of flow meter measurements: Venturi tube, orifice plate and rotameter. Finally, the different types of wears and discharge below a floodgate and design of a floodgate are presented in experiment No. nine.

Also, this manual contents on the details and procedures of working these experiments such as: description of experiment, practical possibilities of devices, specifications of devices, theoretical basis, objectives of experiment, experimental procedures, display of results and questions for discussion.

Thanks to God that helped me to complete this manual.

Ahmed K. Alshara

Misan

2015

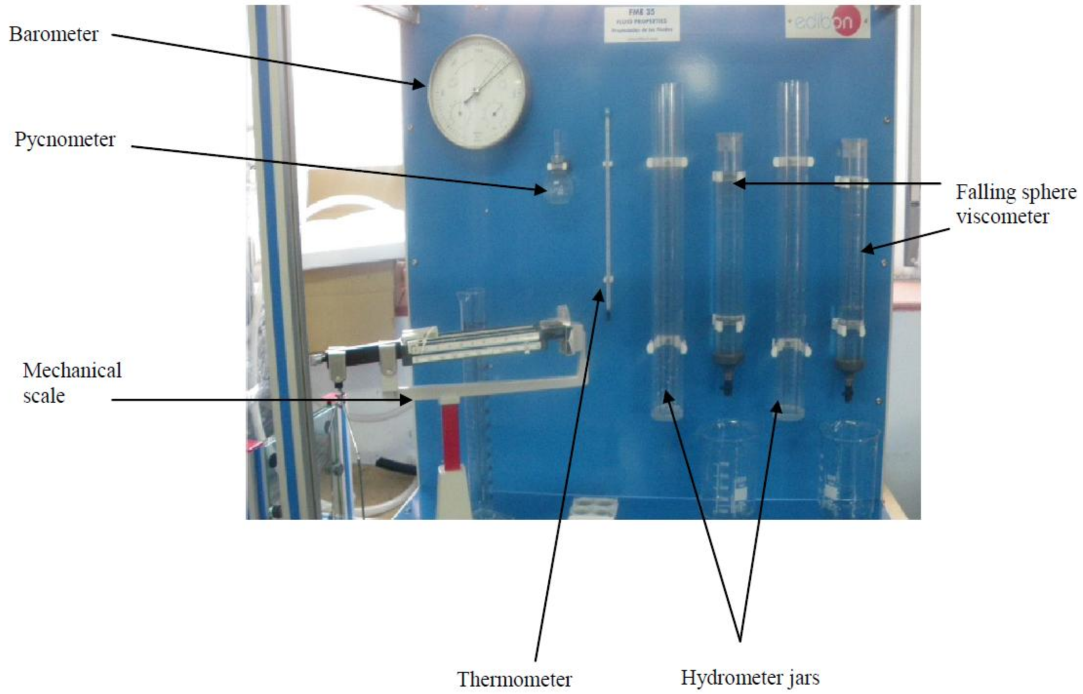
Contents

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.



Capillary tubes module

Parallel sheets capillary module

Specifications

- Anodized aluminum profile frame that guarantees a good stability and resistance to the environment.

- 3 hydrometers of resolution 0.002°SG:

- Hydrometer 0.8ºSG - 1ºSG

- Hydrometer 1ºSG – 1.2ºSG

- Hydrometer 1.2ºSG – 1.4ºSG

- Two hydrometer jars of 450 x 50 mm.

- Aneroid barometer. Range: 973 – 1047 mbar.

- Thermometer with a range between -10 and 50ºC.

- Pycnometer of 50 ml.
- Parallel sheets capillary module.

- Capillary tubes module with tubes of different size: 5mm, 4mm, 3 mm, 2.2 mm, 1.7 mm and 1.2 mm.

- Two falling sphere viscometer tubes of 300 x 40mm with marks at 0, 25, 175, 200 and 220.

- Set of INOX AISI 304 steel balls of different sizes: 3.175 mm, 2.381 mm and 1.588 mm.

- Variable scale mechanical lever balance to be used with the Archimedes module, up to 310 gr.

- Archimedes' module: displacement vessel, bucket and cylinder.

- Graduated cylinder made of glass (250ml.)

- 2 beakers made of glass (600 ml.)

- Digital chronometer.

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.

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.

$$\rho = \frac{mass\ of\ liquid}{volume\ occupied} = \frac{m}{L^3}$$

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 V_w the volume of water, ρ_l is the density of the liquid and ρ_w is the density of water, then:

$$S = \frac{\rho_l . V}{\rho_w . V} = \frac{\rho_l}{\rho_w}$$

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.

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 (F_g =m . g)

b) The buoyant force F_e

c) The viscose resistance to motion F_v

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

mg - F_e -F_v = 0

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

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

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:

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

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

Experimental procedure

1-Density

- 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.
- Make the following table

Liquid	Specific density	Density
Water		
Glycerin		
Engine oil		

2- Capillarity

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.

3-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

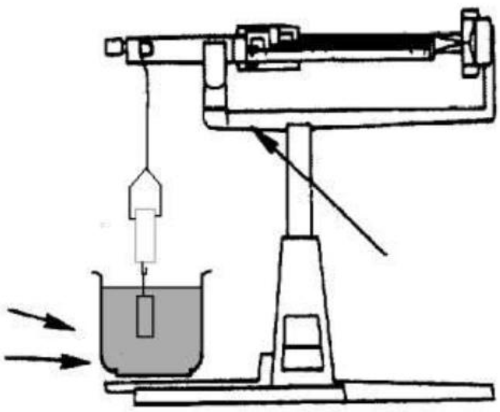
- Prepare the scale to measure between 0 and 0.25 Kg.

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



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.

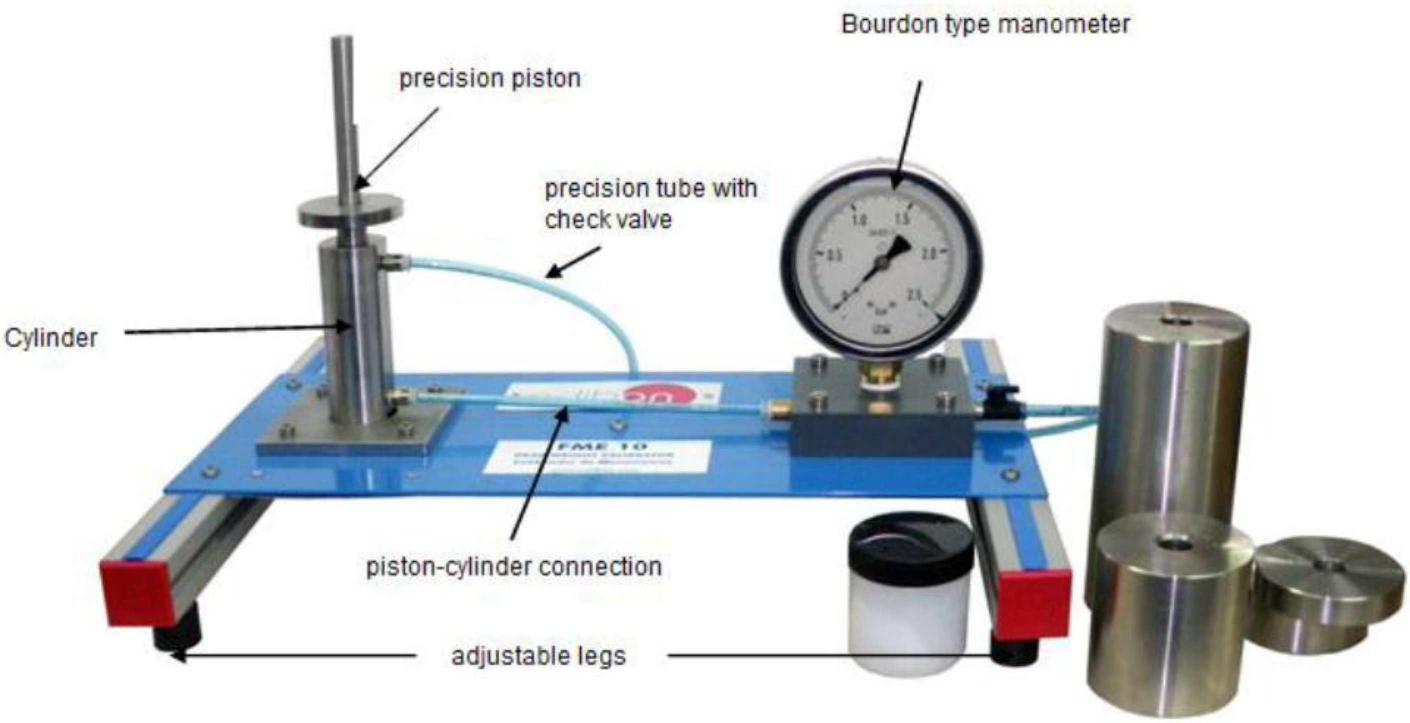
- Repeat the same operation with the other balls.
- Complete the table below:

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

Experiment No.2

Dead weight calibrated



Specifications

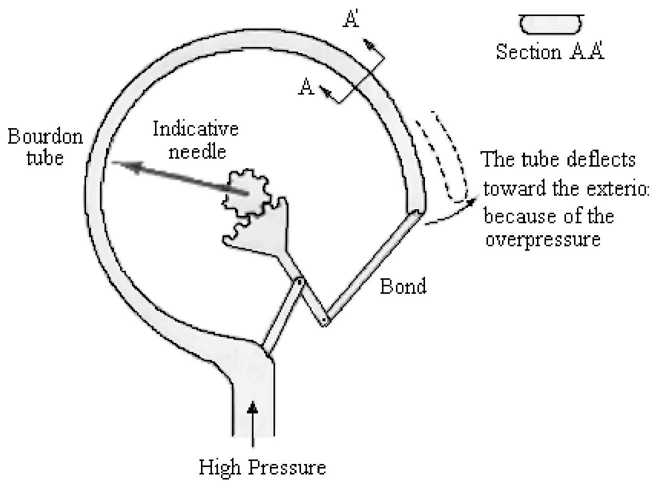
- Bourdon manometer: 0-2.5 bar

- Set of masses. Approximate weights:
- 0.5 kg.
- 1 kg.
- 2.5 kg.
- 5 kg.

- Diameter of the piston: ***18 mm*** approximate
- Weight of the piston: ***0.5 kg***

Bourdon manometers

Bourdon manometers correspond to the group of direct pressure displacement meters. It is a reliable instrument. An outline of this type of manometers is presented in figure below curved tube with smoothed traverse section will be deflected toward it was when it is internally pressurized. A bond with an indicative needle can measure the deflection. With a correct design we can get an extreme reliability, of the order of ±0.1 % of the scale of commercial instruments.



Pressure in a fluid
The force per unit of area is called *pressure **P*** of the fluid

The unit of pressure according to the International system is the **Pascal (Pa).**
1 Pa = N/m^2
1 bar = 10^5 N/m^2 = 10^2 kN/m^2 = 10^5 Pa
1 kg/cm^2 = 10^4 kg/m^2 = 98070 Pa = 0.98 bar

Experimental procedure
1-Calibration of a Bourdon manometer
1. We should have a precision balance to determine the weight of the piston and masses previously.
2. Place the equipment on a flat and even surface and connect the supply tube that connects the inferior area of the cylinder to the input of the manometer by means of a push-in fitting. The output of this manometer should be prolonged, by means of a flexible tube, from the drainage valve until its free end is settled inside an empty recipient to avoid splashes.
3. Disassemble the piston and determine accurately its weight.
4. Also determine the weight of the masses (if it has not been previously made).
5. Cover the piston with Vaseline for a best operation.
6. Fill the cylinder with water or oil.
7. Open the valve of the manometer.
8. When the air of the system has been eliminated, put the one way valve in the flexible tube that comes from the upper part of the cylinder. Later on, close the output valve of the manometer and, immediately later, stop introducing water in the equipment. We will have the whole system full of water then.
9. Introduce the piston totally inside the cylinder.
10. Repeat these steps adding to the piston, in a staggered way, the different masses of the given set of weights.
11. Once completed the test, remove the piston and dry it. Lastly, empty the cylinder.
12. Do not leave the piston inside the cylinder when it is not being used.

Calculations and results

Complete the following table with the obtained values: Gravity acceleration: g = 9.8 m/s

Area of the piston: 254.46×10^{-6} m^2

Mass of the piston Kg	Pressure in the cylinder KN/m^2	Manometer readings Bar	Manometer readings KN/m^2	Absolute error KN/m^2	Relative error %

Draw the following graphs at the suitable scale:
Graph 1 - Absolute error in function of the real pressure in the manometer.
Graph 2 - Relative error in function of the real pressure in the manometer.

Questions
Q.1 Find out the possible discrepancies among the values of the contrasted manometer and the values of the pressure calculated inside the cylinder.
Q.2 Is the relative height (the one that exist among the positions of the patron system and the manometer) important for the contrasting?

2-Determination of the hysteresis curve: The procedure will be the same that the one exposed in practice 1, keeping in mind that, in first place, the given weights will be being introduced in upward order of masse inside the cylinder. Once concluded the series of four masses, we will retire the mass of approximately 5 kg, after few seconds this mass should be introduced again in the cylinder, carrying out the same process in descending order of masses.

It is very important that the given masses were evaluated in a precision balance.

Questions
Q.1. Plot the measurement provided by the Bourdon manometer and the weight (real pressure) provided by the balance.
Q.2. Does hysteresis take place? In affirmative case, to what can it be due?

Experiment No.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, $\Delta h=(h_B - h_A)$:

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

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

$$P_B - P_A = (P_B=\rho.g.h_B) - (P_A=\rho.g.h_A) = \rho.g.(h_{\mathbf{B}}-h_A) = \rho.g.\Delta h$$

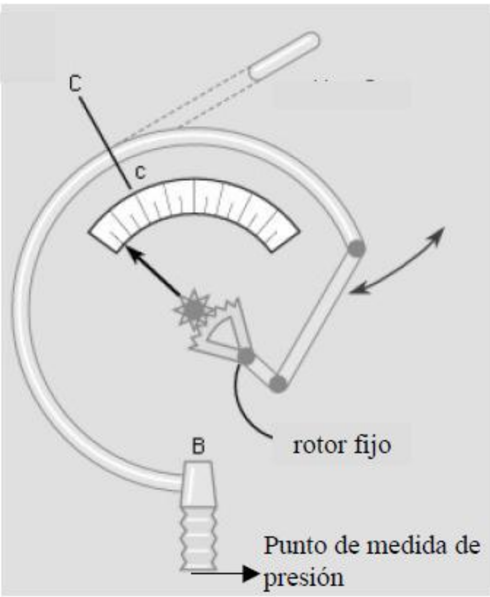
Devices to measure hydrostatic pressures

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:

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

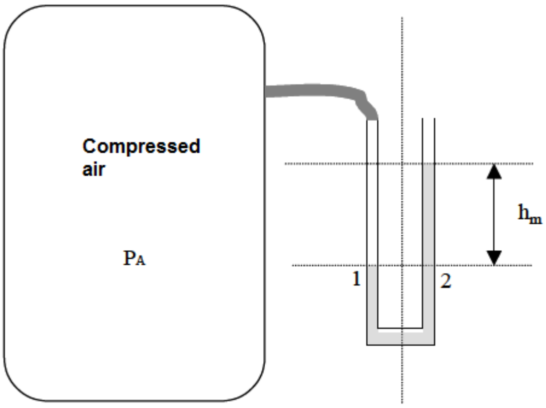
Where:
P: pressure that interests us (absolute pressure).
P_a: atmospheric pressure exerted over the free surface of the liquid.
Z: depth to which the pressure exerted by the liquid wants to be known.
γ: specific weight of the liquid under study.

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:

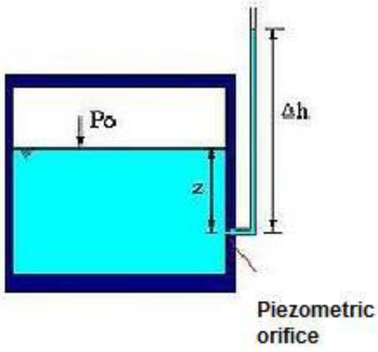
$$P_A = \rho_m.g.h_m + P_{atm}$$

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

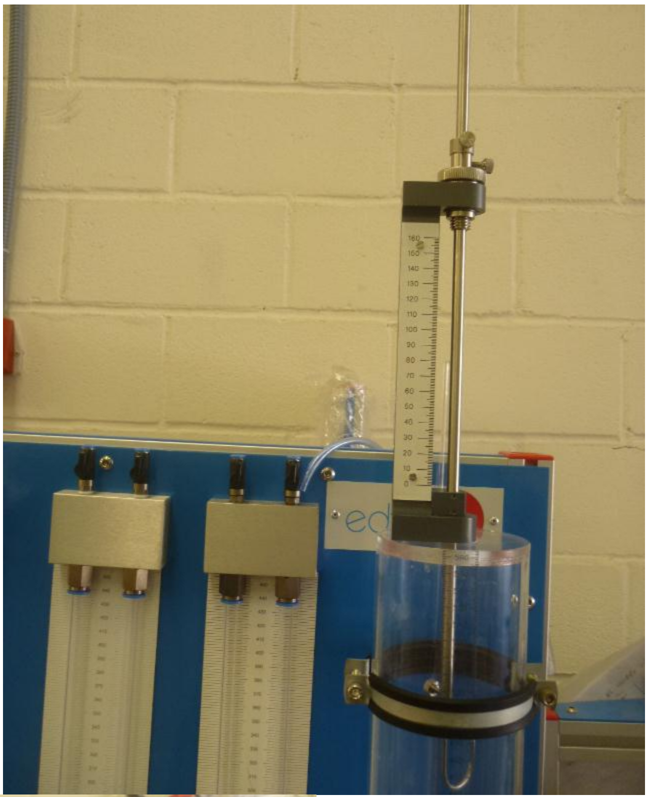
1. Close all the valves of the manifold that connect the tank to the manometric tubes so that water in the tank cannot leak.

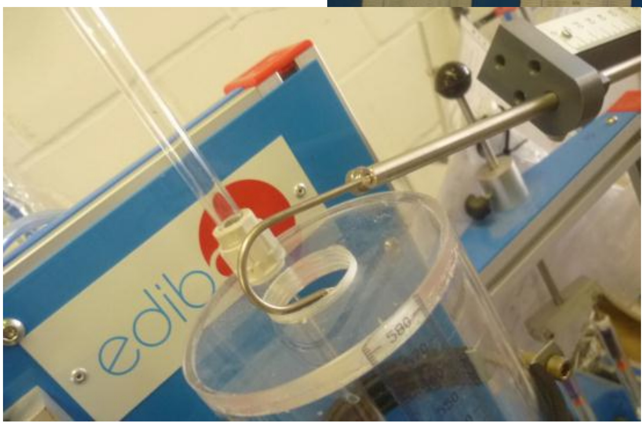
2. Fill the tank with water up to the desired level and check that the level does not vary.

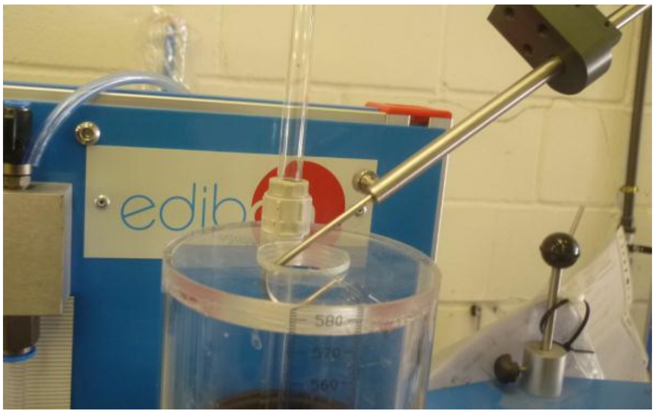
3. Use the gauge in such a way that the point of the hook indicates the current water level in the tank. Record the value indicated on the scale of the gauge.

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.

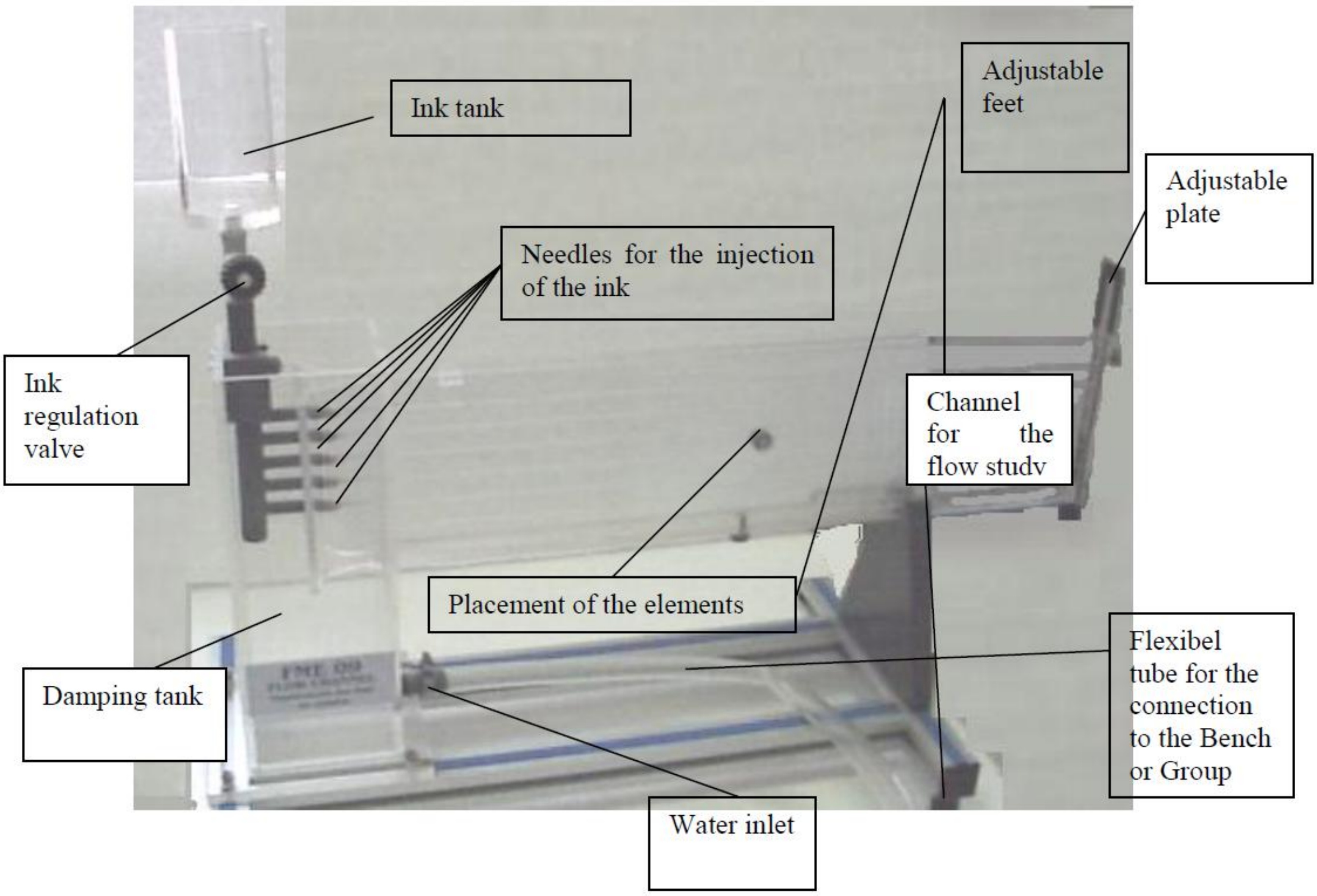
Experiment No. 4

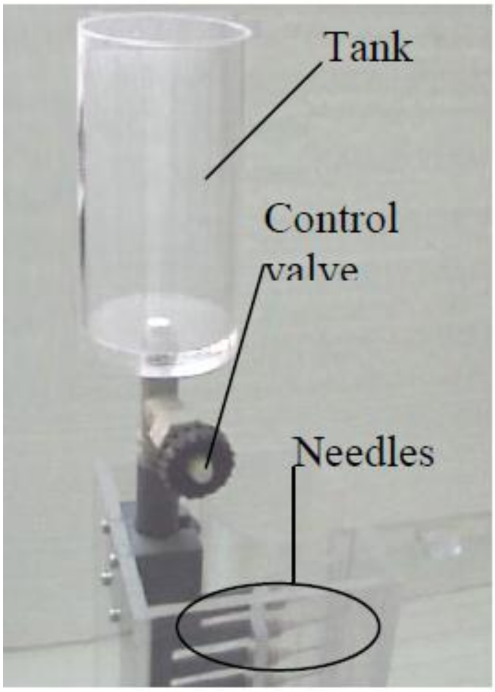
Visualization of the flow in the channels

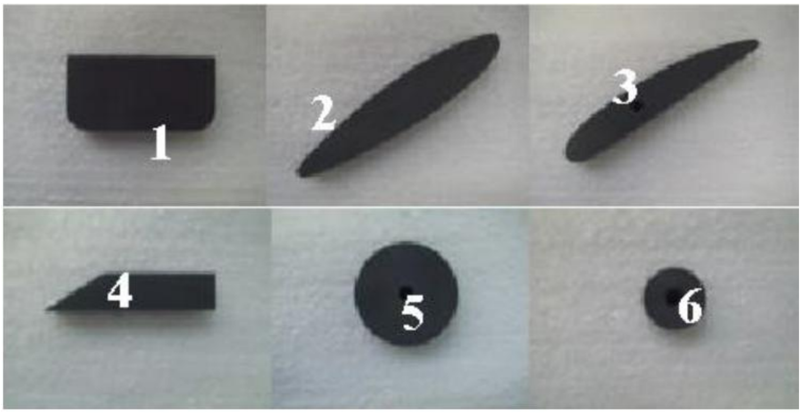
The equipment of Visualization of the flow in Channels is an accessory of the Hydraulic Bench, or Hydraulic Group, that consists of a transparent channel of methacrylate with an overflow pipe on top and an adjustable plate in the discharge end. This plate allows to regulate the flow level.

The water supplied to the channel from the pulse mouth of the Bench or Group, by means of a flexible pipe, passing through a damping tank that eliminates the turbulences. It has an injection system of coloring that consists of a tank, a flow control valve and some needles that allow a better visualization of the flow around the different hydrodynamic models, placed in the middle of the channel. The equipment allows its graduation by using adjustable feet.

Several hydrodynamic models are given to study the flows around them.







Practical possibilities

Visualization of the flow lines around different submerged hydrodynamic models.

Visualization of the limit layer phenomenon.

Specifications

- Capacity of the coloring tank: 0.3 liters.

- Approximate width/length of the channel: 15/630 mm.

- Approximate depth of the channel: 150 mm.

- Hydrodynamic models:

- Two lengthened.

- Two circular of 25 and 50mm diameter.

- Rectangle with rounded edges.

- Wedge.

Theoretical basis

When a fluid flows next to the contour of a solid, the friction force exercised by the latter on the fluid originates a decrease of the velocity of the fluid in contact with the solid. If we consider some points located on a perpendicular to the contour of the solid, as it moves away from the its walls, the distribution of velocities increases. The region where the velocity change takes place is called **limit layer**.

The different models supplied will allow to visualize the following phenomena:

1º Leakage of liquids by weirs.

2º Bodies submerged in a flowing current. Aerodynamics.

Models with wing profile submerged in a fluid current. Aerodynamics

Objectives

We study the movement in a fluid when it takes place around a fixed body. Although that is not completely exact because of the different formation of the turbulence, we can consider that the problem is the same if the obstacle remains fixed and the body moves as if the body moves within an immobile fluid.

Experimental procedure

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

Four different models are supplied with the equipment: two of them with wing profiles and the other two masses with round edges. Thanks to the vegetable ink

(fluorecine) we will see in practice, depending on the flow, how do the current lines behave when they find a certain obstacle.

Experimental procedure

1. Place the model to be used in the channel with the setscrews supplied. Wedge models (as well as circular ones) will be placed in the central hole, created to that purpose.

2. In case we don't use any model, we must place the screws supplied for this situation: for the practical procedure, the non-used hole will be covered with the screw.

3. For a better visualization of the flow, we must use an ink, injected through the hypodermic needles. They must be located at the channel inlet. We will regulate the ink outlet with the pointer of the main valve of the proportioner.

4. It is recommended to use a vegetable ink with density similar to that of the water, so the flow lines are clear. The use of fluorceine is recommended.

5. Start the pump in order that the water begins to circulate through the channel, being the ink control valve closed. Adjust the flow through the channel with the control valve of the Hydraulic Bench or Group and regulating the channel outlet floodgate. To study submerged bodies in a fluid current, we will slide the trap from top to bottom, in order that the water covers the models completely (those will be fasten with the screw and hole located at the side of the channel). As we increase the flow with the control valve of the Hydraulic Bench or Group flow, we get down the adjustable plate in order to avoid a water overflow at the top of the channel.

6. Open the ink control valve located in the base of the tank and adjust the current density.

7. Once the corresponding flow model has been visualized, stop the pump and remove the model from the channel, placing the corresponding screw instead.

8. Repeat this procedure with all the models supplied. With the discharge adjustable plate at the highest position, the channel will operate full of water, allowing the visualization of the flow with flow models around and over submerged objects. For a lower level, move the adjustable plate as indicated in section "installation of the equipment".

9. To see the visualization of the flow lines clearly, we can place a blank sheet at the back of the channel.

10. See how the lines vary depending on the flow when we increase this flow progressively.
11. Vary the inclination angle of the hydrostatic models.

Questions

Q.1. Draw the profile of the current lines for at least four different flows and the same inclination angle.

Q.2. When can we notice the presence of little whirlpools, with low or high flows? Why are they formed?

Q.3. Where does the profile suffer a negative pressure, at the top or at the bottom of the profile?
Q.4. Does the inclination angle have any influence in the current lines?
Q.5. Does the form of the model have any influence?

Circular models submerged in a fluid current. Aerodynamics.

Objectives

We study the movement of a fluid when it takes place around a fixed body. Although that is not completely exact because of the different causes of the turbulence, we can consider that the problem is the same if the body moves and the obstacle remains fixed, as if the body moves within an immobile fluid

Experimental procedure

The experimental procedure is the same for circular models as for wing profile models.

Questions

Q.1. Draw the current lines for all circular profiles, for at least four different flows.
Q.2. Does the diameter of the model have any influence?
Q.3. Are whirlpools created? If they are, which is the reason?

Experiment No.5

Pitot static tube.

Description

The change in flow speed within a tube can be determined with this unit. The Pitot static tube can be moved across the whole cross-section of the pipe and, thus, the pressure profile can be measured. This tube is connected to a manometer through hoses. The position of the measuring head relative to the bottom edge of the tube can be measured on a scale.

Specifications

Pitot tube.
Composed of 8 static holes and total pressure tapping D-2.5 mm.
Transparent tube.
32 mm internal diameter and 430 mm length approx.
Hose connections.
Water manometer, 480 mm length.
Easy and quick coupling system built-in.

Practical possibilities

1- Study of the function of a Pitot static tube.

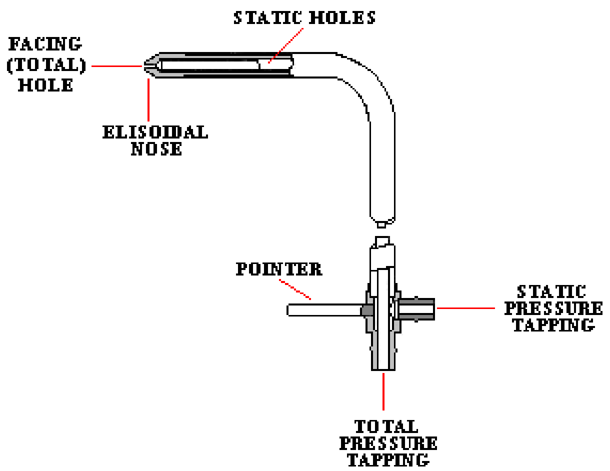
2- Use of a Pitot static tube.

3- Determination of flow speed profiles in a pipe.

4- Demonstration that flow speed is proportional to the pressure difference between total pressure and static pressure.

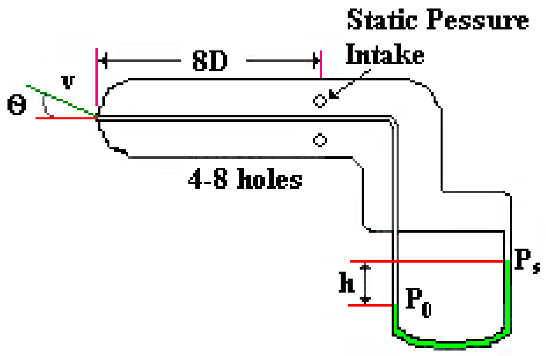
Pitot tube

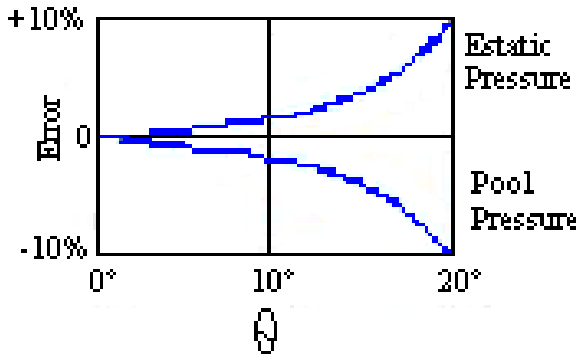
At its head the Pitot tube features a modified ellipsoidal nose with a single forward facing hole for sensing Total Pressure, and a ring of side holes for sensing Static Pressure. These inlets are individually connected by concentric tubes leading to the outlet at the tail of the tube. The entire tube is round to facilitate its entry through the pipe's wall. A tail fitting with a direction pointer is provided, so that the Pitot tube can be accurately aligned inside the pipe.



It is made entirely of stainless steel with welded joints; the tube can be safely exposed to temperatures up to 680ºC or up to 800ºC for short periods.

The basic instrument is the Pitot tube, drawn in below figure. It has holes in the walls to measure the static pressure and a hole in the front to measure the pool or impact pressure, since there the current decelerate until null velocity.





The main disadvantage is that the tube should be perfectly aligned with the current whose direction cannot be known; this produces errors in the measures of Ps and P0, as it is shown in below figure. For example, with an angle of 10º, the static pressure is 2 % bigger that its value with respect to the dynamic pressure and that of the pool is 3 % smaller, so there is a 5% of total error in the difference P_0-P_s.

The velocity is:

$$V_s \approx V = \left[\frac{2(P_0 - P_s)}{\rho}\right]^{1/2}$$

Bernoulli’s equation

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

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

And, in this equipment, z_1=z_2 and P=γ.h.

That is, we want to demonstrate with the practical exercises that in one given pipe with two sections, 1 and 2, the energy between its sections is constant. The sum of the three previous terms is constant. Thus, Bernoulli’ theorem can be

shown as:

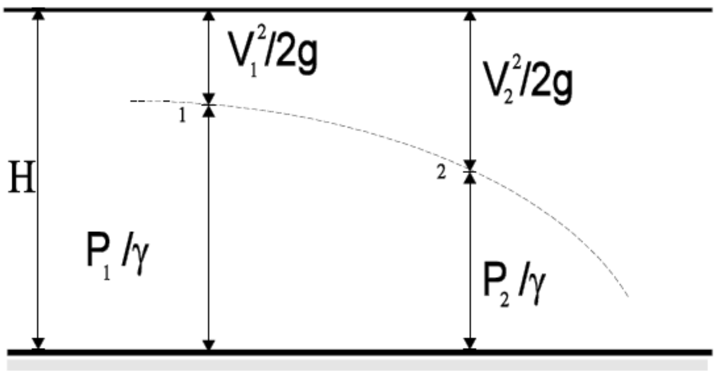
$$H = \frac{P}{\gamma} + \frac{V^2}{2g}$$

Where

$$\frac{V^2}{2g} = \text{kinetic height}$$

P/γ=h= piezometric height. It is the height of one water column related to the pressure of the gravitation field.

Graphic representation of Bernoulli's theorem



In our theory the fluid is considered to be ideal, but particles are grazing each other. In this process, the velocity of the particles is decreased and the energy of the system is transformed into heat.
We consider that the ΔH is the pressure loss between two sections, so

$$\Delta P = \rho \cdot g \cdot Q \cdot \Delta H$$

Where:

$$\Delta H = \frac{\Delta P}{\rho g Q},$$ ΔP is the potential loss.

So, we consider Bernoulli's equation as:

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

Determination of the exact section of the one tube

Practical procedure
1.- Connect the unit to the hydraulic bench or hydraulic group and connect the pipe with the quick connector. Introduce the end of the pipe in the Pitot tube.
2.- Fill all the manometric tubes as indicated in previous section.
3.- Open the flow valve of the hydraulic bench slowly.

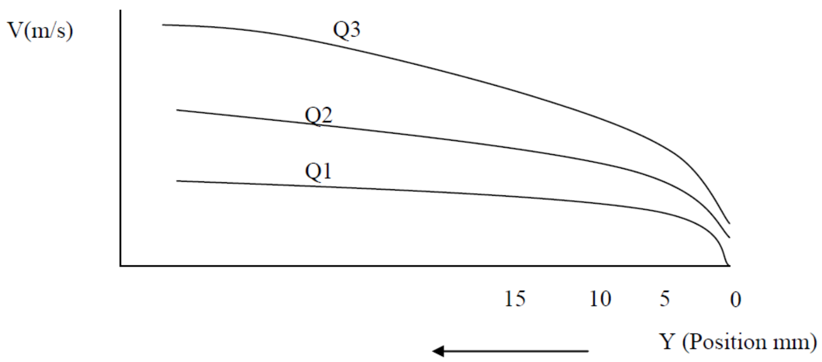
4.- Fix the water flow.
5.- When the heights of both tubes are stable, determine the difference of

height between the two manometric tubes; static pressure and total pressure (Pitot tube).
7.- This difference corresponds to the kinetic pressure given by “V2/2g”.
8.- Determine the section by the following equation: S=Q/V, where Q is the water flow and V is the water velocity obtained in the previous section.
9.- Repeat all the previous steps for different water flows.

Determination of the tube flow speed profiles

Practical procedure
1.- Connect the unit to the hydraulic bench or hydraulic group and connect the pipe with a quick connector. Introduce the end of the pipe in the Pitot tube.
2.- Fill all the manometric tubes as indicated in the previous section.
3.- Open the flow valve of the hydraulic bench slowly.
4.- Fix the water flow.
5.- Place the Pitot tube to the bottom of the pipe and write down the measurement of the Pitot tube at that point.
6.- Move the Pitot tube slightly to the top and write down the measurement of the Pitot tube.
7.- Repeat the measurement placing the Pitot tube in all positions along the pipe.
8.- Repeat the experiment with other flows.

Results and conclusions
Represent in a graph the position of the Pitot tube with the measurement of the Pitot tube and obtain the different speed profiles in the pipe.



Speed profiles

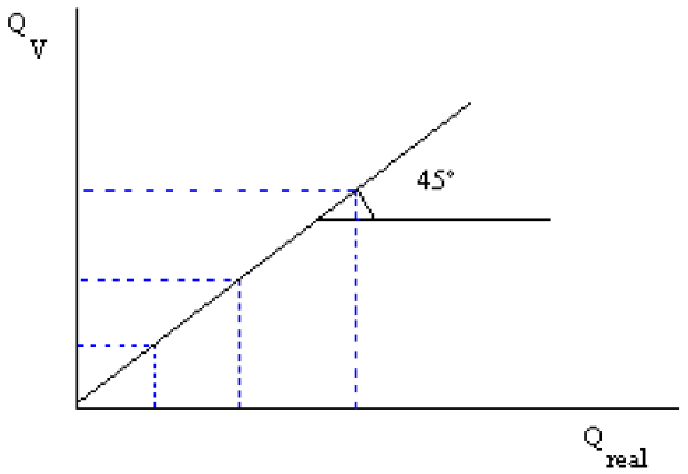
Measure error determination using the Pitot tube

Experimental procedure
With this simple exercise, the difference between the flow measurement with the hydraulic bench and the calculated flow from the mathematical expressions will be observed.
Put the Pitot tube in the middle of the pipe and connect the hydraulic bench pump. Write down the pressure measured with the Pitot tube and the flow measured with the hydraulic bench.

So, the real volume Q_r (the flow introduced in the unit) will be directly given by the electromagnetic flowmeter. It is supposed that the volume measured with the Pitot should be the same (there is no loss) and it will be given by the following expression:

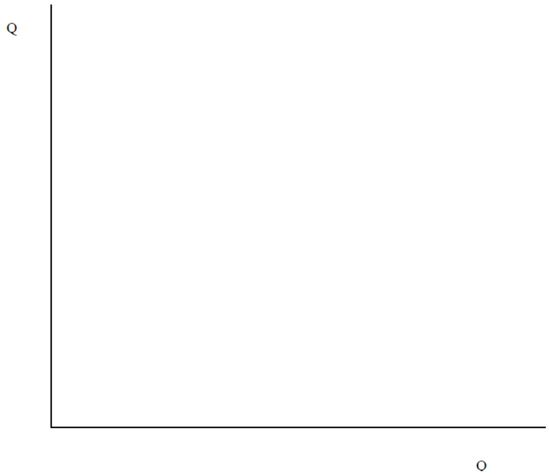
$$V_s \approx V = \left[\frac{2(P_0 - P_s)}{\rho}\right]^{1/2}$$

Where:
V: Water velocity (m/s)
P_0: Total pressure at that point
P_s: Static pressure at that point
$(P_0\text{-}P_s)$: Pressures difference in mmH_2O
γ : Water specific weight
NOTE: Be careful when introducing the units in the equation.
If the flow is mathematically represented, calculated and compared with the real flow, the following should be ideally obtained:



However, although a straight line is obtained, $Q_{real} \neq Q_v$, because an experimental factor must be introduced.

Q (l/min) electmg	$(P_0\text{-}P_1)$ mm H_2O	V	Q (l/min)



Finally, to determine the error it is necessary to take into account that it is defined by the difference between the actual volume and the volume obtained with the Pitot tube.

Questions

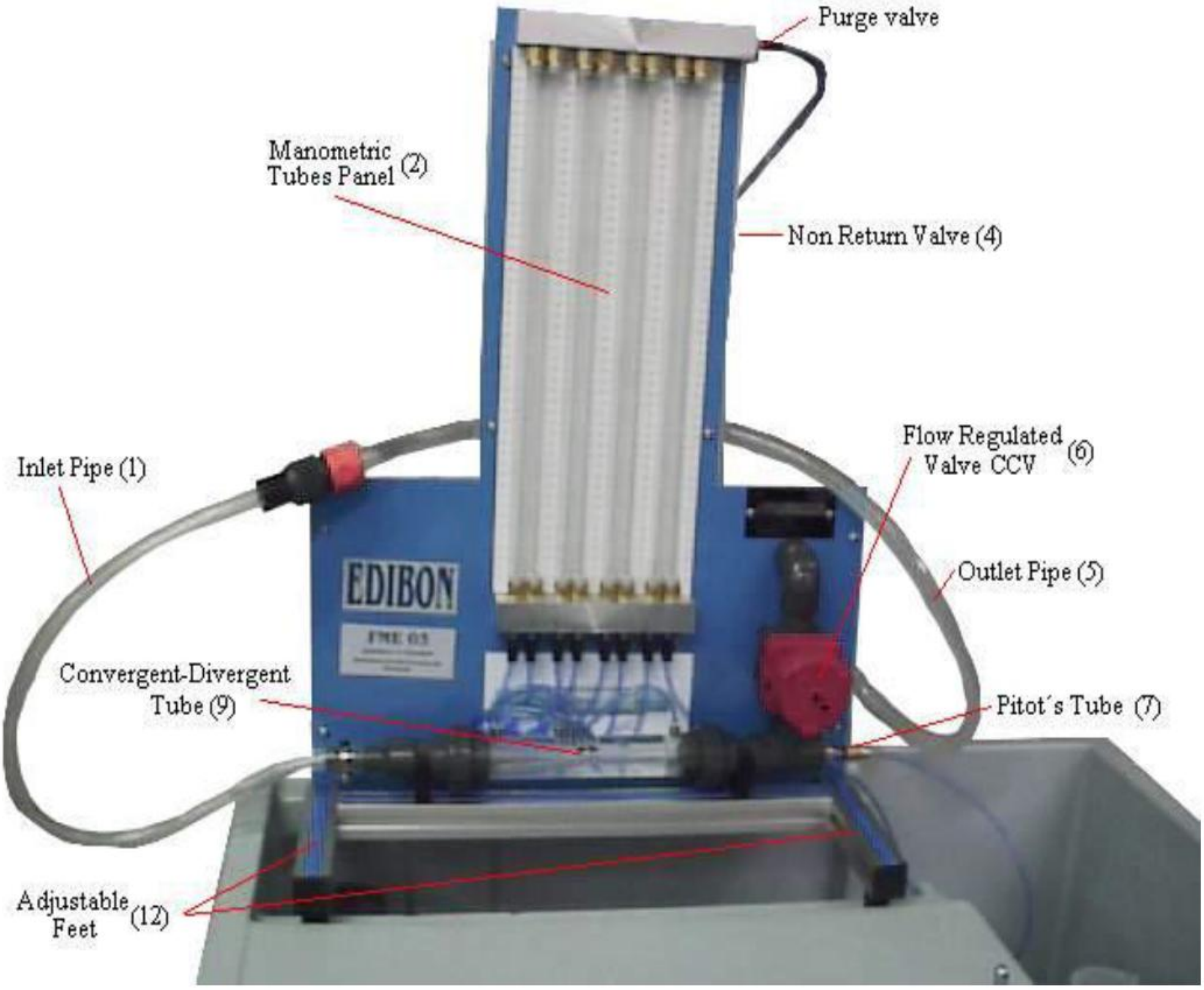
Q.1. It is supposed that the error is given by a constant but if the error depends on the volume, when and why does it happen?

Experiment No.6

Bernoulli´s Theorem Demonstration

The Bernoulli´s Theorem Demonstration equipment is mainly composed by a circular section conduit with the shape of a truncated cone, transparent and with seven pressure valves that are able to measure, simultaneously, the static pressure values corresponding to each point of seven different sections. All the pressure valves are connected to a manometer of pressurised or not pressurised 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 height in every section (dynamic pressure). The flow rate and the pressure in the equipment can be modified by adjusting the control valve and by using the supply valve in the Hydraulics Bench.

A flexible hose attached to the outlet pipe (5) is directed to the volumetric measuring tank. For the practice, the equipment needs to be assembled on base board of the bench and has adjusted legs to level the equipment. The Inlet pipe ends in a female coupling, which may be connected directly to the bench supply.



Specifications

- Rank of the manometer: 0 - 300 mm of water.

- Number of manometric tubes: 8.

- Upstream strangulation diameter: 25 mm.

- Narrowing: Upstream narrowing: 10º & Downstream narrowing: 21º

Practical possibilities

1: Determination of the exact section in the Venturi's tube.
2: Proof of Bernoulli's Theorem and its limitations concerning its divergent convergent position.
3: Direct measurement of the static electricity and total height distribution along a Venturi´s tube.

Bernoulli's equation

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

where, in this equipment, $z_1=z_2$. ; and $P=\gamma.h$

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

That is, we want to demonstrate with these practices that in one given pipe with two sections, 1 and 2, the energy between its sections is constant. The sum of the three previous terms is constant and so, Bernoulli' theorem can be shown as:

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

where :
$\frac{V^2}{2g}$= Kinetics height
$\frac{P}{\gamma}=h$= piezometric height: It is the height of one water column associated with the pressure of the gravitation field.

With pressure losses, we consider **Bernoulli's equation** as

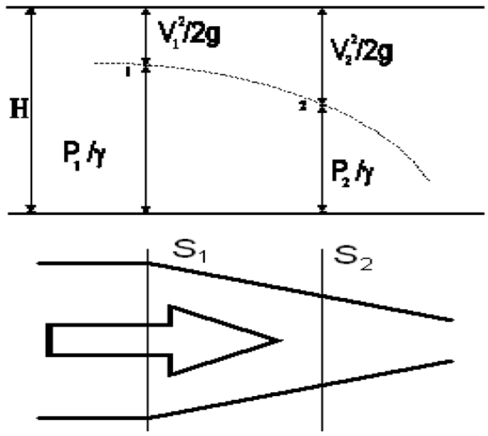
$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+Z_2+\Delta H$$

where ΔH is the pressure loss between both sections

$$\Delta H = \frac{\Delta P}{\rho g Q}$$

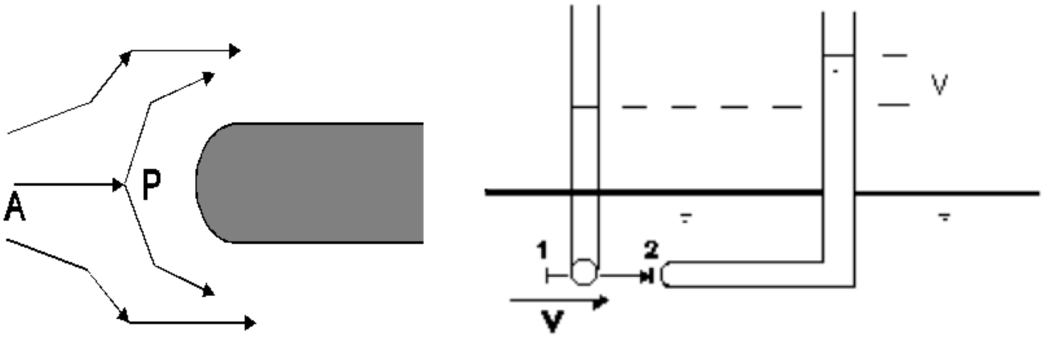
where: ΔP is the potential loss.

Graphic representation of Bernoulli's theorem



Pitot's tube

The operation with Pitot's tube is: First of all, we consider a fix obstacle in the moving fluid



The ΔP line finishes in the impact point (P), if we make an orifice in this point P and we link it with a manometric tube, we are measuring the total pressure.
We can also know the velocity in the pipe, that is:

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

Where:
V1 = V (Particles velocity), V2 = 0

$$\frac{V^2}{2g} = \frac{P_2 - P_1}{\gamma} = \Delta h \quad \rightarrow \quad V = \sqrt{2\, g\, \Delta h}$$

How to fill the manometric tubes

In this section, we explain the procedure to be followed for a correct filling of the manometric tubes.
1. Close the flow control valve of the Hydraulic Bench or Group (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 the CV. It is important to maintain this order of closing, because if do not, the manometric tubes will empty of water.

3. It is very important that the equipment is a watertight compartment.

4. Remove the non-return valve or open the purge valve.

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

6. When all the tubes have obtained the desired height (70 or 80 mm), close the CCV valve and put the non-return valve or close the purge valve.

7. In this moment, all tubes have the same water level.

Determination of the exact section in Venturi's tube

Practical procedure

1.- Connect the equipment to the hydrostatic bench or hydrostatic group in convergent or divergent direction. Direction is not very important in this experiment.
2.- Fill all the manometric tubes as indicated in the previous section.
3.- Open the flow valve of the hydrostatic bench and the regulation valve of the equipment.
4.- Fix the water flow, and write down its value.
5.- 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.
6.- When the heights of both tubes are stable, determine the difference of height between the two manometric tubes; static pressure "h_i" and total pressure "h_{Tp}" (Pitot's tube).
7.- This difference corresponds to the kinetic pressure given by "$V^2/2g$".
8.- Determine the section by the following equation: S=Q/V, where Q is the water flow and V is the water velocity obtained from the previous section.
9.-Repeat all the steps described in the previous practices for each pressure taking.
10.- Repeat all the previous steps for different water flows.

11.- For each water flow, the section must be more or less the same. Make the average of the sections obtained with different water flows. We recommend a water flow of 5 l/min, 10 l/min and 15 l/min for this experiment.

Questions and results

With these values, complete the following tables:

	Q_1= $v_1 = \sqrt{2g(h_{TP} - h_i)}$	Q_2= $v_2 = \sqrt{2g(h_{TP} - h_i)}$	Q_3= $v_3 = \sqrt{2g(h_{TP} - h_i)}$
h_{TP}-h_1			
h_{TP}-h_2			
h_{TP}-h_3			
h_{TP}-h_4			
h_{TP}-h_5			
h_{TP}-h_6			

	$A_1 = \frac{Q_1}{v_1}$	$A_2 = \frac{Q_2}{v_2}$	$A_3 = \frac{Q_3}{v_3}$	$\langle A \rangle$= $(1/3)*(A_1+A_2+A_3)$
h_{TP}-h_1				
h_{TP}-h_2				
h_{TP}-h_3				
h_{TP}-h_4				
h_{TP}-h_5				
h_{TP}-h_6				

Q.1 To what is the difference between A_1, A_2 and A_3 due to?
Q.2 Why does the pressure measured by the Pitot tube decrease along the pipe?

Demonstration of Bernoulli´s theorem and its limitations in divergent-convergent

Practical procedure

1.- Place the equipment is convergent-divergent position according to water flow direction.
2.- Connect the inlet pipe to the quick connector of the hydraulic bench.

3.- The other pipe is located in the drain of the bench.
4.- Fill the manometric tubes as indicated in the previous section.
5.- Move the Pitot's tube towards the position of the first pressure taking. Write down the height obtained through both manometric tubes (static and Pitot's tubes).
6.- Move the Pitot's tube towards the next manometric pipe and write down the reading.
7.- Repeat the previous steps for each pressure taking.

Questions and Results

Q.1 Comment the validity of Bernoulli's Equation for the system tested for
a) Convergent flow

b) Divergent flow

Q.2 Write down in the following table the data obtained.

For each value, determine the fluid velocity for each narrowing position. Determine the kinetic height at each tapping position.

Add the theoretical kinetic height to the static height measured in order to determine a total theoretical height.

Flow m^3/s	**Section*** m^2	**Mean velocity** m/s	**Kinetic Height** MWC	**Piez. Height** mWC	**Kin.+Piez. Height** mWC	**Pitot** mWC

* These sections have been calculated experimentally in the first practical exercise.

Q.3 Do these total heights match up with the total height measured with the probe?

If they are different, what are the reasons?

Note: The manometric panel does not indicate the true profile of static pressure along the test section.

Demonstration of Bernoulli´s theorem and its limitations in convergent-divergent position

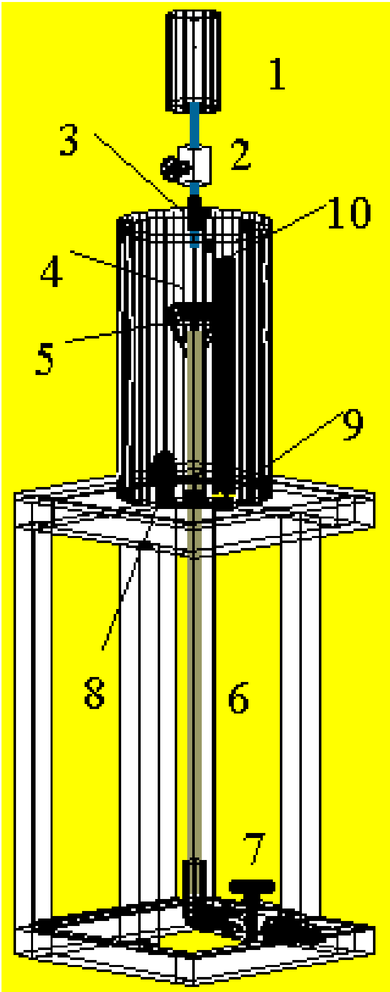
Repeat the previous experiment. In this case, change the transparent element of the equipment in order to study the phenomenon in the convergent-divergent direction.

Experiment No. 7

Reynolds number

Description

The unit consists of a cylindrical tank with a glass nozzle coupled to a methacrylate tube, which allows us to visualize the fluid, an overflow that guarantees the homogeneity of the flow and a needle coupled to a vessel from which the coloring matter is supplied. Water supply is supplied through the base of the tank with the hydraulic bench or hydraulic group.



1.- Tank for including ink.
2.- Colouring liquid injection valve
3.- Screw
4.- Inyector
5.- Nozzle
6.- Visualization Flow Tube
7.- Flow Control Valve
8.- Inlet pipe.
9.- Overflow Outlet Pipe.
10.- Overflow

The visualization of the laminar or turbulent régime can be carried out by mean the flow control valve.

Specifications

- Inside diameter of the glass tube: 10 mm.
- Outside diameter of the glass tube: 13 mm.
- Rehearsal pipe length: 700 mm.
- Capacity of the coloring matter vessel: 0.3 liters.
- Diaphragm Flow control valve.

The colored fluid is regulated with a needle valve.

THEORY

Reynolds number

The Reynolds number, R, is used as useful parameter to classify the régime type in a flow. The determination of the Reynolds number is a function of the critical velocity of the fluid. The critical velocity is defined as the fluid velocity in which flow regimen is changed; laminar to turbulence. Osborne Reynolds demonstrated that two types of currents could be established inside a pipe.

He managed to classify the type of current regardless the size and type of pipe by means of a dimensionless parameter, Reynolds' number.

- **Laminar regime flow.** A laminar regimen is when the fluid only has traslation and deformation movements, the trajectories and flow lines of the different particles of the fluid are arranged in parallel. It can be considered that the movement of the fluid is in layers and they do not mix or cross among them. Under these conditions, the trajectories of the coloring particles can be easily identified as a line. There is a proportionality relation between the load loss and the current velocity. The regime is determined for Reynolds' values lower than 2000.

- **Transition regime flow:** It is the area where there is no clear relation between the load loss and the fluid's velocity. The regime is determined for Reynolds' values lower between 2000 and 4000.

- **Turbulent regime flow.** A turbulent regime is when the particles of a fluid are subjected to traslation, rotation and deformation movements. The flow is chaotic and the current lines are intercrossed. Under these conditions, the coloring matter spreads in the water and the trajectory of its particles can not be observed. The load loss is proportional to the square of the velocity. It is due to the forming of turbulences and refluxes inside the tube. The regime is determined for Reynolds' values higher than 4000.

The number is defined by this formula:

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

Being:

ρ: the fluid's density [kg/m^3].

u : its velocity [m/s].

μ : dynamic viscosity [kg/m*s].

d : diameter of the tube [m].

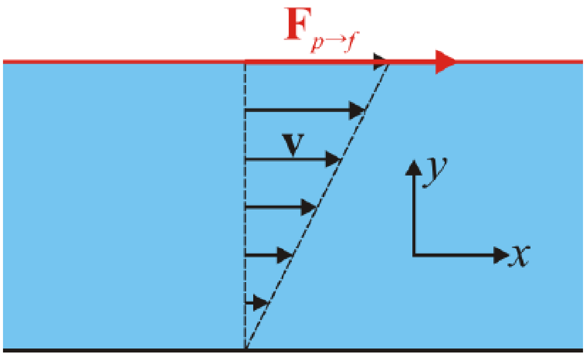
Kinematic viscosity μ and dynamic viscosity ν can be related by means of the following expression. It is obtained by working out the Reynolds' number value in the formula.

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

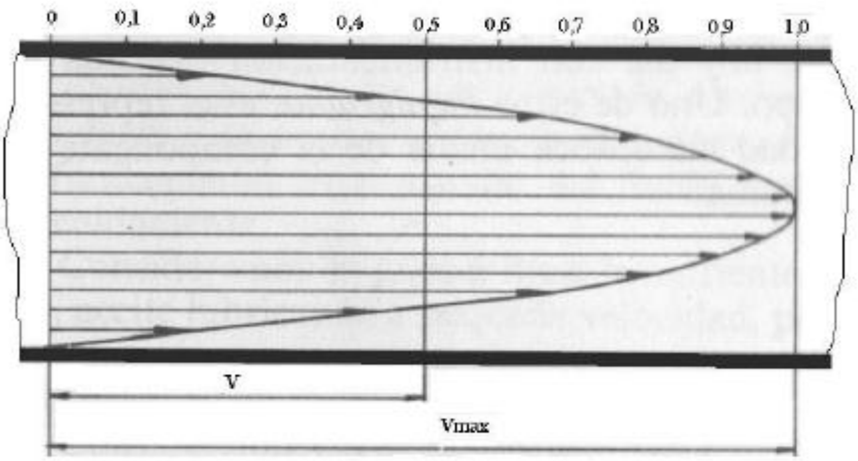
$$R = \frac{u \cdot d}{\nu}$$

Then, Reynolds' number will be in function of the velocity and the inner diameter of the tube and inversely proportional to the kinematic viscosity.

The easiest case (known as Couette flow) is that of a liquid in the space between two parallel plates, one of them is fixed and the other one moves, dragging the liquid at the same time. The result of the velocity profile, considering the upper plate as movable, would be something similar to this sketch:



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.



Observation of the laminar, transition and turbulent

Objective

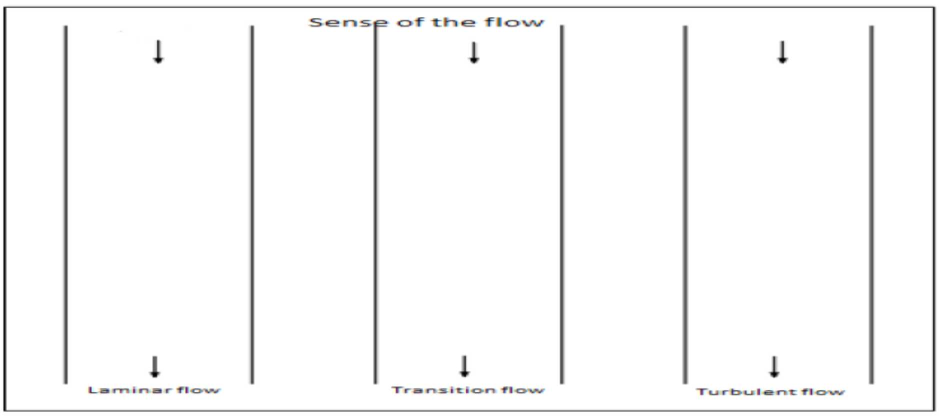
The aim of this practical exercise is to determine visually the conditions which differentiate the laminar, transition and turbulent regime in a fluid (water).

Experimental procedure

1- Fill the tank (1) with approximately 100 ml of water and add 1 ml of coloring matter.
2- The unit FME06 is placed on the channel of the Hydraulic Bench (be careful to not to incline it) or on the surface of the Hydraulic Group.
3- Their feed pipe is connected (8) to Hydraulic Bench or hydraulic group. Place the discharge and drainage hoses in the bench's spillway.
4- 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).
5- Close the flow control valve (7).
6- 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.
7- Open and close several times the flow control valve (7) to purge the visualization tube.
8- Wait until the liquid in the apparatus is steady, at least ten minutes, before going on with the experiment.
9-Start the pump and open the control valve of the bench or of the group carefully until the water comes out for the overflow.
10- 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.
11- 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).
12- 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).

Results

Draw a diagram showing the shape of ink lines inside the tube according to what has been observed under each regime.



Q1. Why does the turbulent flow appear?

Q2 Which of the three regimens is the most adequate one if we want to obtain a fluid as homogeneous as possible?

Classification of the different types of regime according to Reynolds number

Objective

The aim of this practical exercise is to relate the value of Reynolds number to each different regime, the laminar, the transition and the turbulent one.

Experimental procedure

1- Fill the tank (1) with approximately 100 ml of water and add 1 ml of coloring matter.
2- The unit FME06 is placed on the channel of the Hydraulic Bench (be careful to not to incline it) or on the surface of the Hydraulic Group.
3- The feed pipe is connected (8) to the Hydraulic Bench or Hydraulic Group. Place the drainage hose in the bench's spillway and the drainage's tube in the measuring tank.
4- 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).
5- Close the flow control valve (7).
6- Start the pump and fill the tank slowly until reaching the overflow level (10); afterwards close completely the control valve of the Hydraulic Bench or hydraulic group completely to avoid the return of the water, and stop the pump.
7- Open and close several times the flow control valve (7) to purge the visualization tube.
8- Wait until the liquid in the apparatus is steady, at least ten minutes, before going on with the experiment.
9- Start the pump and open the control valve of the bench or of the group carefully until the water comes out for the overflow.
10- 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.
11- 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).
12- 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 (turbulent regime).
13- Measure and write down the flows of each regime. Besides, write down the flow at which the border among them is (flow measurement).
14- Measure the water temperature.

Information

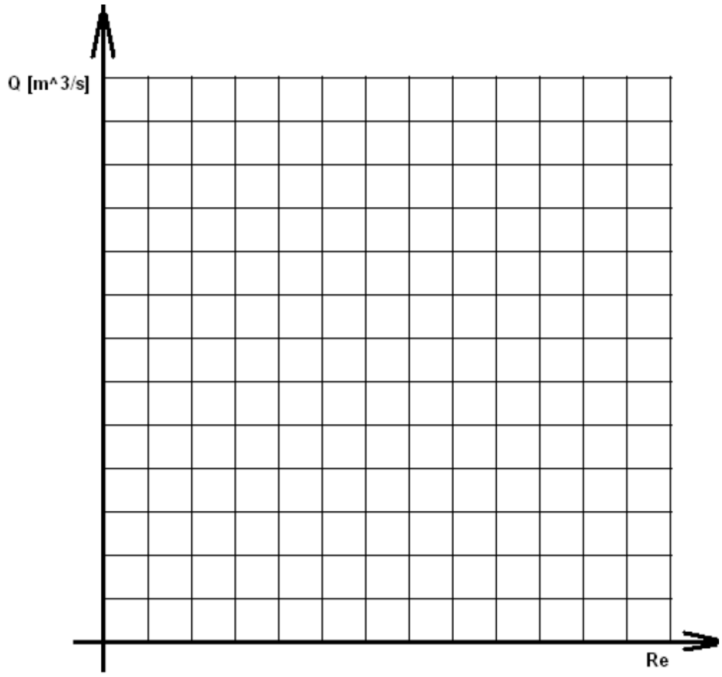
Visualized regime	Measured volume [m^3]	Measure time [s]

Water temperature, θ =

Results

Determine water kinematic viscosity suitable for the measured temperature.
Calculate the flow for each sampling (flow measurement).
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.
With the equation (3) calculate the Reynolds number for each flow.
Fill in the following table:

Visualized regime	Flow [m^3/s]	Velocity [m/s]	Reynolds number



Questions
Q1. How does the Reynolds number change with the flow increase?
Q2. Up to which Reynolds number can a laminar flow be obtained?
Q3. From which Reynolds number range do we obtain a transition flow?
Q4. From which Reynolds number does the turbulent flow appear?
Q5. Do these results have coherence with those obtained by Osborne Reynolds?

Visualization of the parabolic velocity profile

Objective
The aim of this practical exercise is to visualize the velocity profile which is typical of a fluid that flows inside a channel with cylindrical symmetry.

Experimental procedure
1- Fill the tank (1) with approximately 100 ml of water and add 1 ml of coloring matter.
2- The unit FME06 is placed on the channel of the Hydraulic Bench (try not to incline it) or on the surface of the Hydraulic Group.
3- The feed pipe is connected (8) to the Hydraulic Bench or Hydraulic Group. Place the outlet and drainage hoses in the bench's spillway.
4- 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).
5- Close the flow control valve (7).
6- 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.
7- Open and close several times the flow control valve (7) to purge the visualization tube.
8- Wait until the liquid in the apparatus is steady, at least ten minutes, before going on with the experiment.
9- Start the pump and open the control valve of the bench or of the group carefully until the water comes out for the overflow.

10- Open the valve of the ink vessel (2) having the flow control valve (7) closed.

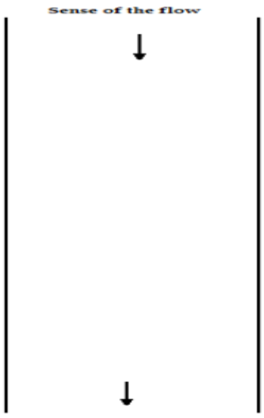
11- Let the ink to be accumulated at the admission nozzle inlet (5) until its inner diameter is completely covered in ink.

12- Open the control valve (7) quickly and observe how the parabolic velocity profile is generated inside the glass tube (6).

13- Repeat the experiment for several openings of the control valve (7).

Results

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



Q1. Why do we obtain that shape in the profile?

Flow measurement

The procedure to carry out this practical exercise is the following one:

1. Check that the unit's inlet and outlet connections are the correct ones:

Inlet hose connected to the pressure intake.
Outlet hose of the unit placed in the measurement tank.
Spillway of the unit connected to the spillway of the bench.

2. Plug the drainage of the Hydraulic Bench (when you have the FME 00 bench) with the valve used for that purpose. 3. Switch on the pump. Take a reference value of the volume and switch on the chronometer at the same time.

4. It is recommended to leave the water running for 1min.

5. Obtain the volume of water collected during the timed period.

Use this formula to calculate the flow:

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

Where:
Q: Flow [m^3/s].
t: Timed period of time [s].
V: Volume collected in the tank [m^3].

Experiment No.8

Flow meter measurement

The accessory consists of a Venturi meter, a variable area meter and an orifice plate, installed in series to allow a direct comparison.
Each element includes one pressure tap at the inlet and one pressure tap at the outlet.

The unit consists of different elements used together with the Hydraulic Bench:
- A quick connection nozzle at the water inlet of the unit that is coupled to the water outlet of the Hydraulic Bench (8)

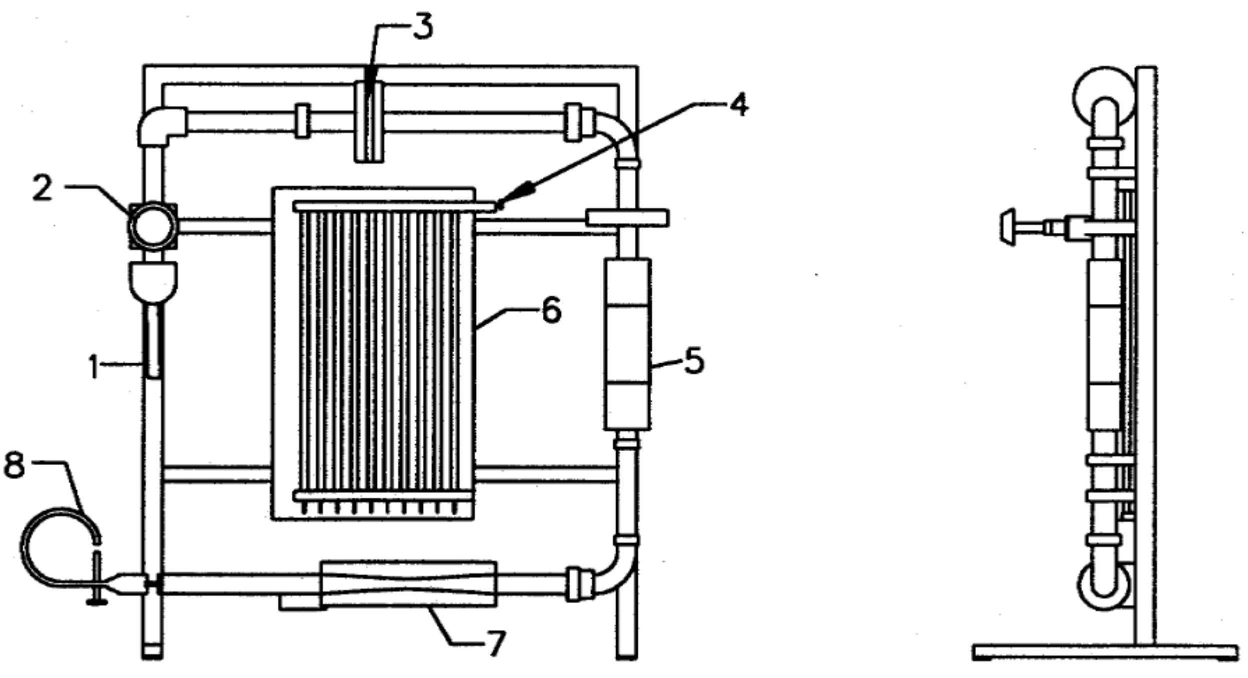
- Venturi meter (7)

- Variable area meter (5)

- Orifice plate (3)

- Flow control valve (2)

- Manometer with 8 tubes (6)



Specifications
- Manometer range: 0 to 500 mm of water column (2mm).

- Number of manometric tubes: 8.

- Orifice plate:

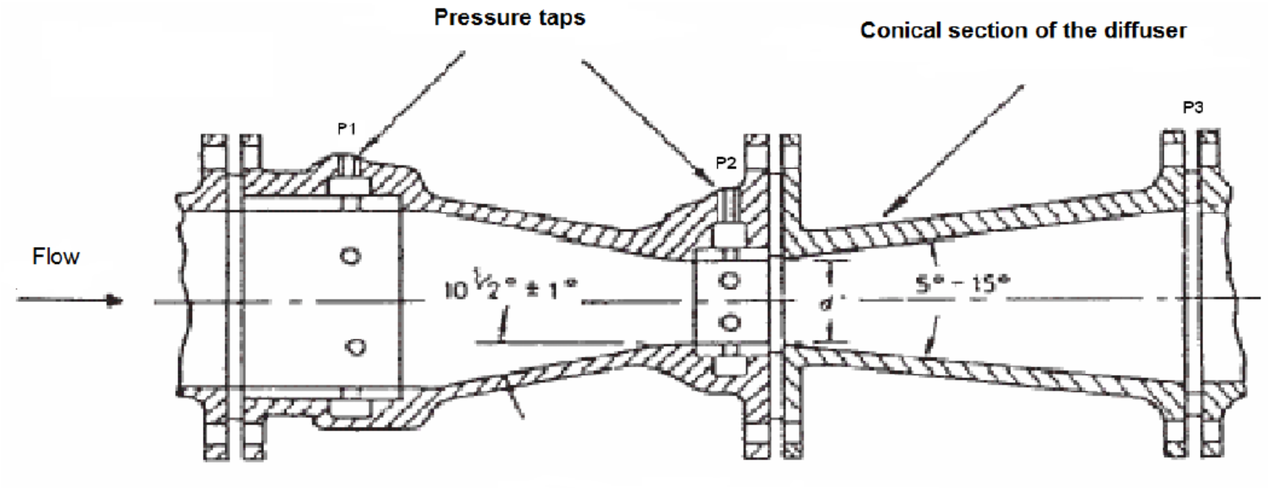
Inlet diameter: 0.0235 m

Outlet diameter: 0.019 m
- Flowmeter: 250 to 2500 l/h

- Venturi tube dimensions:

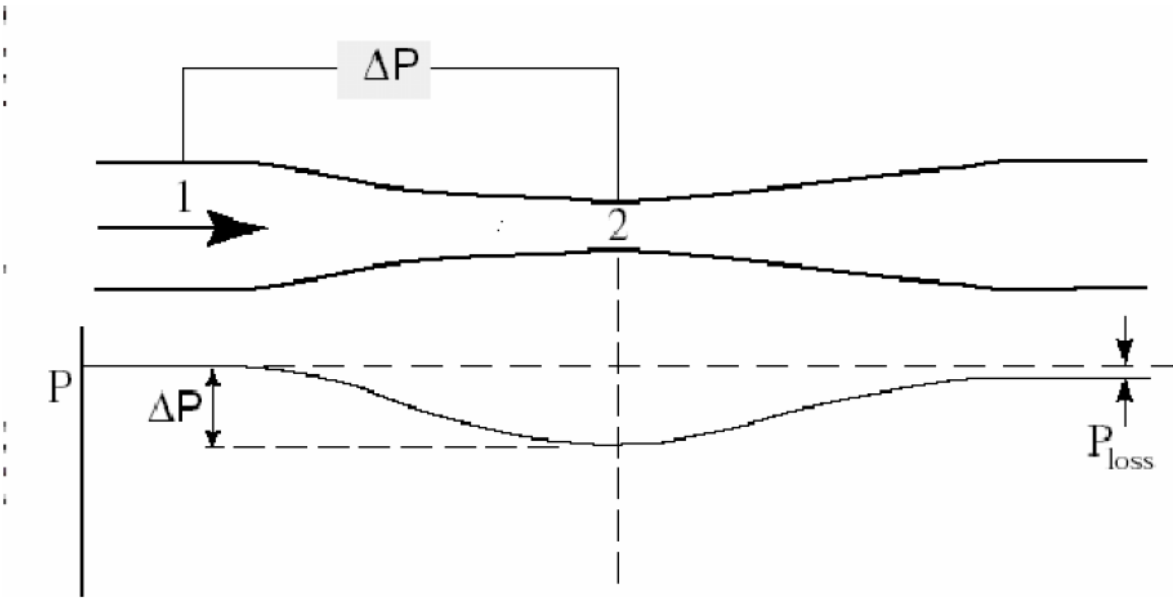
Upstream pipe diameter: 32 mm
D1= 0.032 m
D2= 0.02 m
D3= 0.032 m

Venturi tube



VENTURI TUBE

To obtain accurate results, the Venturi tube must be preceded by a length at least 10 times the diameter of the pipe.
The pressure difference ΔP is measured between the non-turbulent upstream condition (1) and the throat (2). The typical radii relationship is d2/d1=0.5.
The losses due to friction in the pipe generate a constant loss, Ploss, which is normally the 10%-20% of ΔP.



Pressure in the upstream section and the throat are actual pressures, so losses must be considered in the energy conservation equation.
If Bernoulli equation is applied between points 1 (upstream section) and 2 (throat). And taking into account that the energy loss due to the height difference (z1 - z2) is negligible:

$$\frac{P_1}{\rho}+\frac{v_1^2}{2\cdot g}+z_1-h=\frac{P_2}{\rho}+\frac{v_2^2}{2\cdot g}+z_2$$

v1: velocity of the fluid in section 1 [m/s].
v2: velocity of the fluid in section 2 [m/s].
h: energy loss [m].
P1: pressure in section 1 [Pa].
P2: pressure in section 2 [Pa].
g: acceleration due to gravity [m/s^2].
ρ: density of the working fluid [Kg/m^3].
When applying the flow continuity equation:

$$\rho_1 v_1 A_1=\rho_2 v_2 A_2$$

Where:
A1: area of section 1 [m^2].

A2: area of section 2 [m^2].
Since Q = A2 *v*2, neglecting losses *h* the characteristic equation of the meter based on Bernoulli equation for an ideal non compressible flow is obtained:

$$Q_{ideal} = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{\frac{2\Delta P}{\rho}}$$

Where:
ΔP: pressure difference between tap 1 and 2 [Pa].
Transforming the equation:

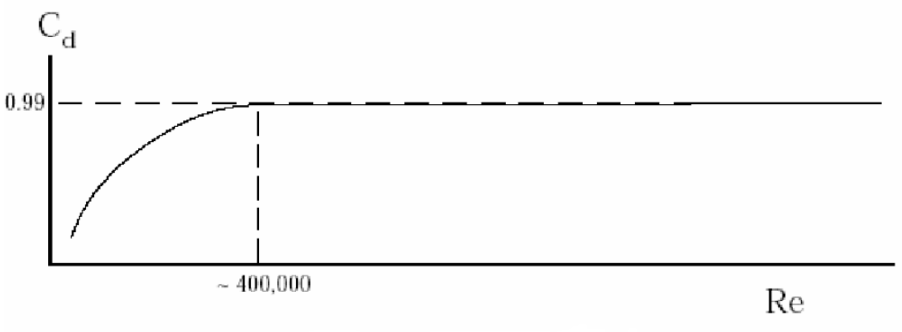
$$Q_{ideal} = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2 \cdot g \cdot \Delta H}$$

Where:
ΔH: level difference of manometric tubes between tap 1 and 2 [m].
g: acceleration due to gravity [m/s^2].

In the actual case with losses, what implies an actual flow, we have:

$$Q_{real} = C_d \cdot Q_{ideal}$$

Where Cd is the discharge coefficient. Cd is obtained by calibration. A typical variation of Cd is shown in the figure below.



Curve of the discharge coefficient C_d

Experimental procedure
Step 1: Connect the hydraulic bench to the unit and switch on the hydraulic bench.
Step 2: Proceed to fill the manometric tubes .
Step 3: Vary the flow of 5 l/min .
Step 4: Take the measurements of the manometric tubes no. 1, 2 and 3.
Step 5: Switch off the hydraulic bench.

Results

Fill the following table.

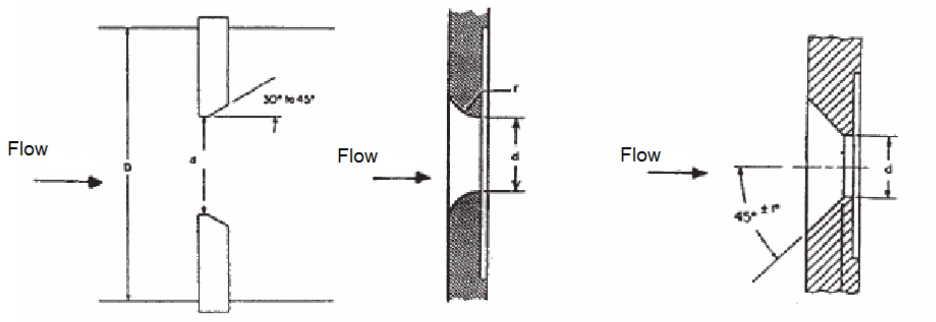
Flow Q l/min	H2-H1 [mm]	H3-H1 [mm]	H2-H1 [mm]

Q.1. Plot the pressure drop between the pressure taps 1-2 and 1-3 versus flow.

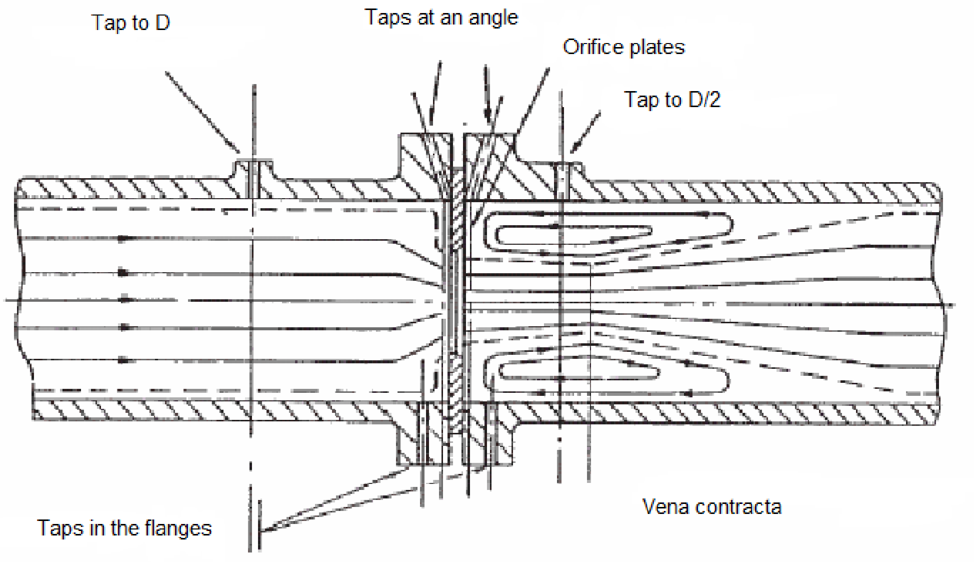
Q.2. Between which taps is the highest pressure drop generated? why?

Orifice plate

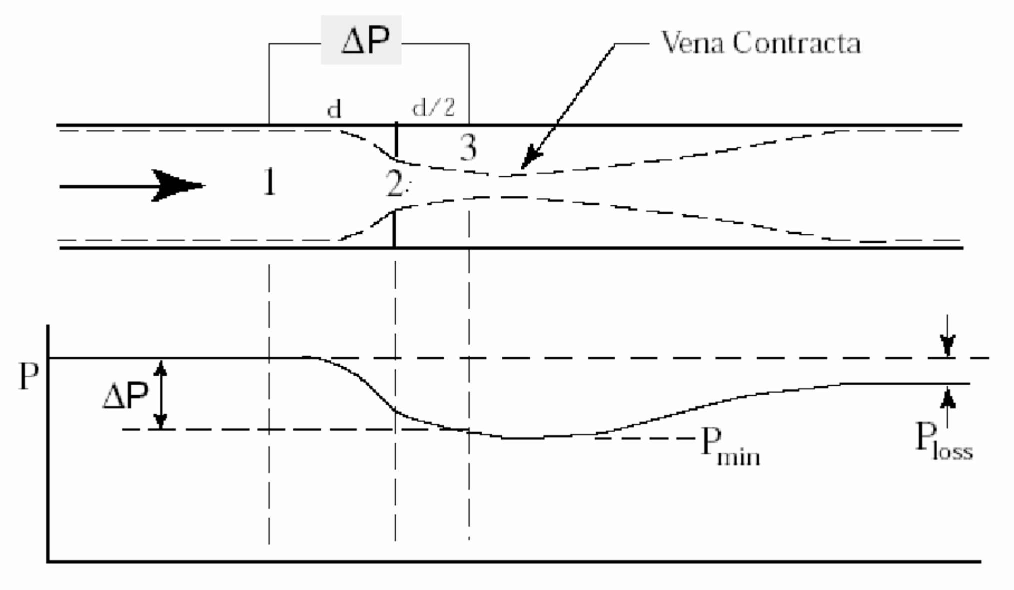
An orifice plate is a flat plate with an orifice. The orifice can be concentric, eccentric or a segment



a) **Sharp edges** b) **Quarter of a circle** c) **Conical inlet**



LOCATION OF THE TAPS



Pressure drop in an orifice plate

Applying Bernoulli equation before and after the orifice plate:

$$Q_{idial} = \frac{A_1 \cdot A_3}{\sqrt{A_1^2 - A_3^2}} \sqrt{\frac{2 \cdot \Delta P}{\rho}}$$

Where:
A1: area of section 1 [m^2].
A3: area of section 3 [m^2].
ΔP: pressure difference between tap 1 and 3 [Pa].

By transforming it we obtain:

$$Q_{ideal} = \frac{A_1 A_3}{\sqrt{A_1^2 - A_3^2}} \sqrt{2 \cdot g \cdot \Delta H}$$

Where:
ΔH: level difference of manometric tubes between tap 1 and 3 [m].
As A3 is the transverse area of the vena contracta and it is unknown, the area of the orifice A2 is used, and the quotient C is added to take into account the difference.

$$Q_{real} = C \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2 \cdot g \cdot \Delta H}$$

Where:
C: corrective coefficient [non dimensional].
ΔH: level difference of manometric tubes between tap 1 and 2 [m].

Experimental procedure
Repeated the same procedures of Venturi meter.

Results
Fill the following table.

Flow Q l/min	H7-H6 [mm]

Q.1. Plot the pressure drop between the pressure taps 6-7 versus flow.

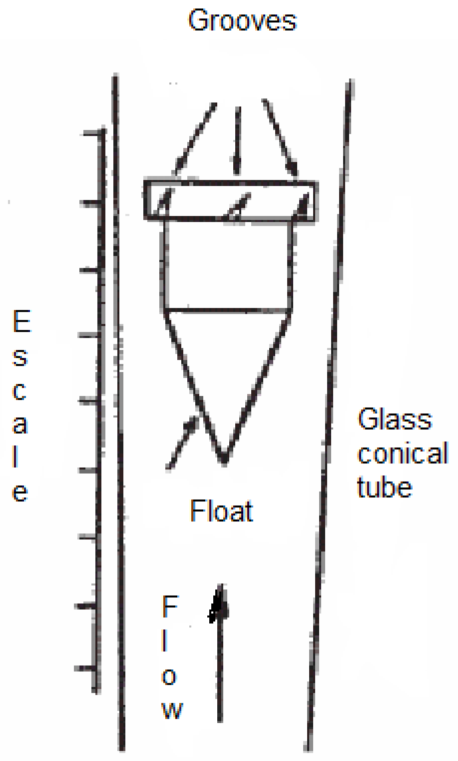
Q.2. What are pressure drops due to?

Variable area meters

Their operation is based on keeping a constant differential pressure, allowing to increase the efficient flow area with the flow rate.
The most commonly used variable area meter consists of a vertical conical tube and a float. The fluid flows upwards through the tube displacing a float, which normally has some

grooves that makes it rotate, providing it stability and the required centering effect. This rotation has originated the name of rotameter.

When there is no flow, the float rests at the bottom of the tube, but when the fluid flows, it makes the float rise in order to keep equilibrium between the pressure drop through the float and the buoyancy and gravity forces acting on it. Since the weight of the immersed float is constant for a given fluid, the pressure loss must also be constant. Therefore, when the flow increases the float will rise in the tube to provide a bigger annular section so the fluid can flow through it.
The height reached by the float is an indication of the flow passing through the tube. If the tube is transparent, it can be directly graduated on the tube in units of flow.
The accuracy obtained with the variable area meters is not usually better than +-2.2% of deflection at full scale, so that they are not recommended when a high precision is required.

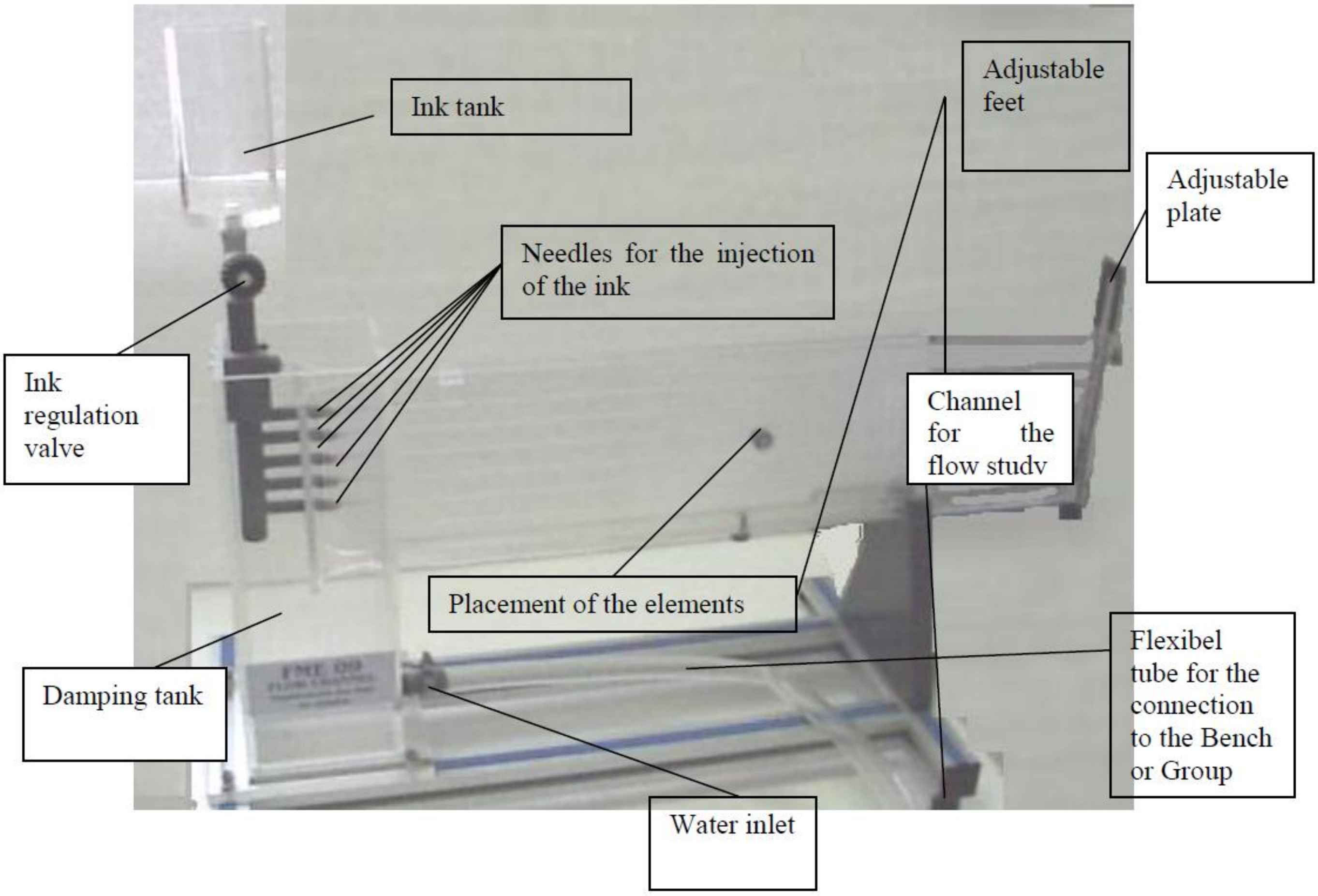


Rotameter with glass conical tube and float

Experiment No. 9

Wears

The equipment of wears in Channels is an accessory of the Hydraulic Bench, or Hydraulic Group, that consists of a transparent channel of methacrylate with an overflow pipe on top and an adjustable plate in the discharge end. This plate allows to regulate the flow level.
The water supplied to the channel from the pulse mouth of the Bench or Group, by means of a flexible pipe, passing through a damping tank that eliminates the turbulences. The equipment allows its graduation by using adjustable feet.



Practical possibilities

Demonstration of the phenomenon associated to the flow in open channels.

- Load loss when passing from quick to slow flow.

- Quick and slow flow in the different types of weirs.

- Discharge below a floodgate.

- Design of a floodgate with an obstacle.

Specifications

- Capacity of the coloring tank: 0.3 liters.

- Approximate width/length of the channel: 15/630 mm.

- Approximate depth of the channel: 150 mm.

- Hydrodynamic models:

- Two lengthened.

- Two circular of 25 and 50mm diameter.

- Rectangle with rounded edges.

- Wedge.

Theoretical basis

When a fluid flows next to the contour of a solid, the friction force exercised by the latter on the fluid originates a decrease of the velocity of the fluid in contact with the solid. If we consider some points located on a perpendicular to the contour of the solid, as it moves away from the its walls, the distribution of velocities increases. The region where the velocity change takes place is called **limit layer**.

The different models supplied will allow to visualize the following phenomena:

1º Leakage of liquids by weirs.

2º Bodies submerged in a flowing current. Aerodynamics.

Leakage of liquids by thin-wall weirs

Objective

To demonstrate the phenomenon associated to the flow in an open channel

Theoretical basis

With this phenomenon a new application of Bernoulli's theorem is studied: the phenomenon of the leakage or pouring of a liquid, when it overflows above a wall called, in this case, WEIR.

The main application of the weirs is the measurement of flows, being able to have different forms, as rectangular, trapezoidal, triangular, etc.

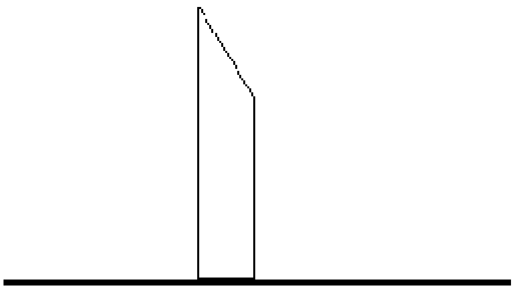
There exist different forms of sheet slopes:

Free sheet: it is the most common, a thin-wall weir where the sheet falls freely, being perfectly ventilated. The current lines are parabolic.

Depressed sheet: When the channel walls don't allow the free access

of air under the sheet. That is the case of our tests.

Adherent sheet: The adherent sheet is the limit state of the depressed sheet when the air confined in the inferior part of the sheet has been completely expelled.
We will be able to see the depressed and adherent sheet with the model of below figure, placing it in the base of the channel and threading the screw of the inferior part of the channel. To be able to place the model correctly, it is necessary to use a bar and a screwdriver.



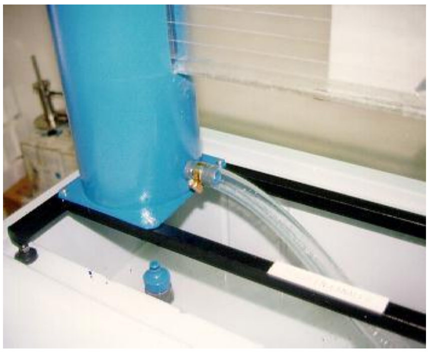
Weir will be defined as an obstruction in the bottom of a channel that should be surpassed by the current. For certain simple geometries, the flow Q is correlated with the height H that, over the weir, has the water upstream. Therefore, a weir is a flow meter, elementary but effective, in open channels.
Both in thin and thick-wall weirs, the flow upstream is subcritical, it accelerates to critical near the top of the weir and it overflows in form of supercritical sheet that splashes the current downstream. In both cases, the flow q for width unit is proportional to $H^{3/2}$, where H is the depth of the current upstream measured from the crest of the weir.

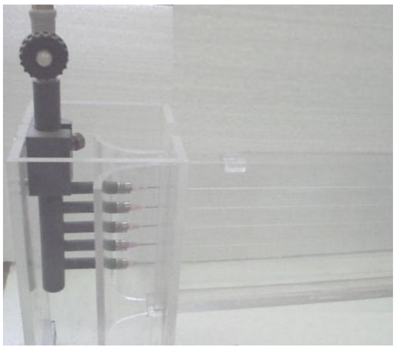
Experimental procedure

1. Place the model in use in the channel using the setscrews supplied. The model will be placed in the appropriate hole in the lower part of the channel.

2. In case of not using any model, it will be necessary to place the screws supplied: for the practical procedure, the hole we are not using will be covered with the screw.

3. For a better visualization of the flow, we should use ink, injected through the hypodermic needles. These must be placed at the channel inlet. We will regulate the ink outlet with the pointer of the main valve of the proportioner.





4. It is recommended to use a vegetable ink with density similar to that of the water, so the flow lines are clear. The use of fluorceine is recommended.

5. Start the pump, in order that the water begins to circulate through the

channel, being the ink control valve closed. Adjust the flow through the channel with the control valve of the Hydraulic Bench or Group and regulating the outlet floodgate of the channel. To study the weirs, lift the adjustable board up, so the water doesn't find any obstruction in the drain. As we increase the flow with the flow control valve of the Hydraulic Bench or Group, we will get down the adjustable plate in order that the water doesn't overflow on top of the channel.

6. Open the ink control valve located in the base of the tank and adjust the current density.

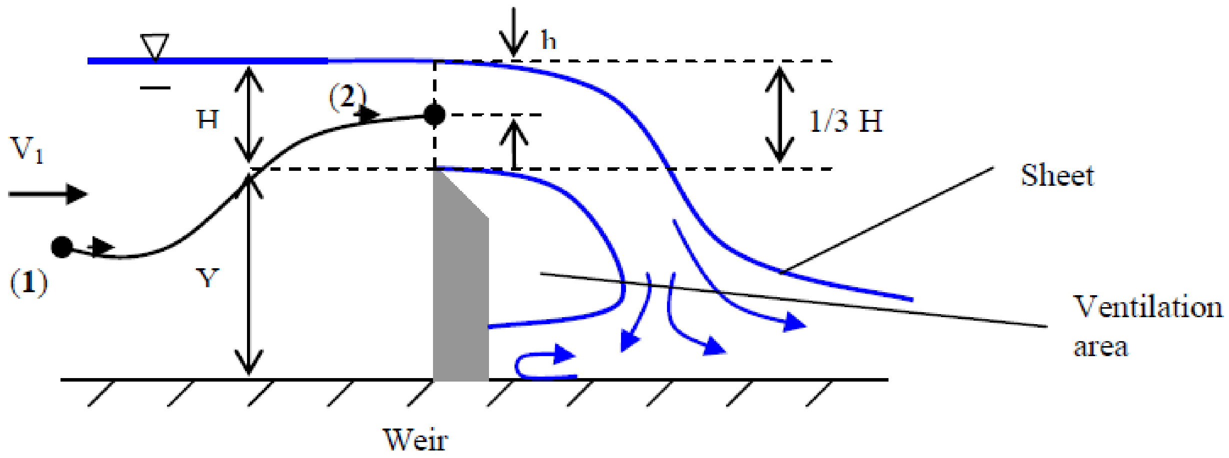
7. Once the model of corresponding flow has been visualized, turn off the pump and remove the model from the channel, placing the corresponding screw instead.

8. To see the visualization of the flow lines clearly, we can place a blank sheet at the back part of the channel.

9. Measure the heights upstream of the weir for different flows. Take note of the flow obtained by the Hydraulic Bench or Group.

Questions

Q.1 We will analyze the flow in weirs, without taking into account the friction and by using the potential theory.



We will estimate the velocity distribution *V2(h)* over the weir by using the Bernoulli's equation, which refers to point 1 upstream of the figure

$$\frac{V_1^2}{2g} + H + Y \approx \frac{V_2^2}{2g} + H + Y - h$$

$$V_2^2 = 2gh + V_1^2$$

Then, the flow over the weir will be, approximately:

$$q = \int_{H/3}^{H} V_2 dh = \int_{H/3}^{H} \left(2gh + V_1^{\,2}\right)^{1/2} dh = \frac{2}{3}(2g)^{1/2}\left[\left(H + \frac{V_1^{\,2}}{2}\right)^{3/2} - \left(\frac{H}{3} - \frac{V_1^{\,2}}{2g}\right)^{3/2}\right]$$

where it is accepted that the free surface has a height of *2H/3* over the weir. Normally, the kinetic height upstream is worthless, so we will
use the following equation:

$$q \approx 0.81 \frac{2}{3}(2g)^{1/2} H^{3/2}$$

For different flows introduced, check that this relation is true. If it isn't, why can that have happened?

For this question, we will take data from flows given by the Hydraulic Bench or Group.

Q.2 Although the previous formula is correct, coefficient 0.81 is too high. Normally, we use the following equation, where a weir coefficient (C_W) is introduced:

$$q = \frac{2}{3} C_w (2g)^{1/2} H^{3/2}$$

Being the height for different flows known, determine the coefficient of the thin-wall weir.

Q.3 The previous formula was obtained in 1929 by T. Rehbock:

$$C_w \approx 0.611 + \frac{0.075H}{Y}$$

where *Y* is the weir height and *H* the height measured over the channel.
Does the Rehbock's formula coincide with the values obtained experimentally?
Q.4 The previous formulas determine specific flows. From the weir height, the depth upstream measured and the weir width, estimate the total
flow.
Q.5 Do the flows experimentally calculated, taking the weir as flowmeter, coincide with the flows given by the Hydraulic Bench or Group? If there are any difference, which could be the reason?

Liquid leakage by thick-wall weirs

Objective

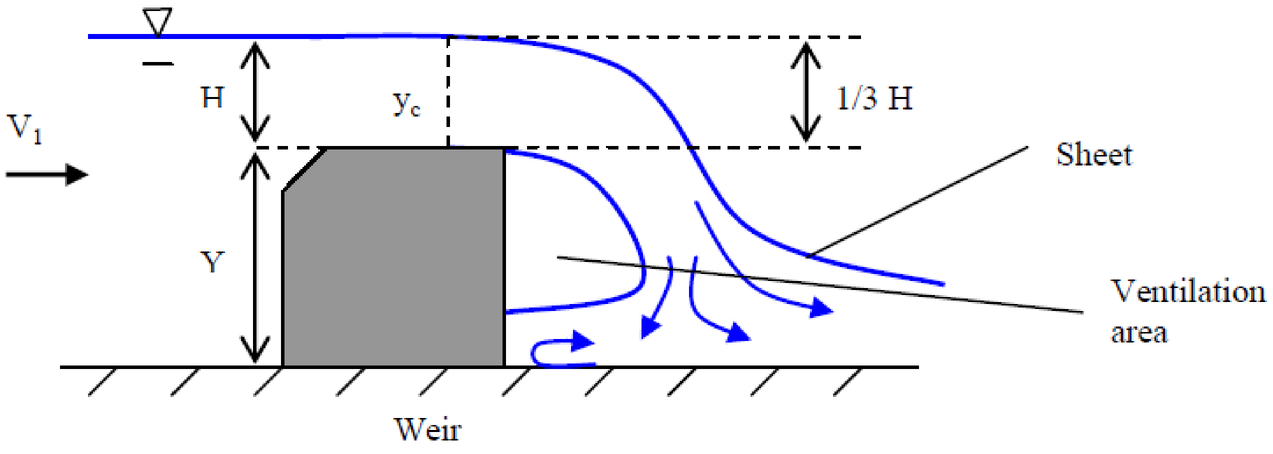
Demonstrate the phenomenon associated to the flow in an open channel.

Experimental procedure

With the other model supplied, we can study the **thick-wall weir:** the experience shows that when the liquid passes through a thick-wall weir, its free surface decreases and it adopts the form of below figure.

The steps we must follow in which concerns to the equipment operation are the same previously described in practice 1.

Questions



Q.1 In the thick-wall weir of above figure, a unidimensional current is created, whose conditions are almost critical. If we use Bernoulli's equation upstream until the top of the weir, we obtain:

$$\frac{V_1^{\,2}}{2} + H + Y \approx \frac{V_c^{\,2}}{2g} + y_c + Y$$

As $V_c^2 = g y_c$, the previous equation will be simplified to:

$$y_c \approx \frac{2H}{3} + \frac{V_1^{\,2}}{3g} \approx \frac{2H}{3}$$

where we use the same hypothesis as for a thin-wall weir. We ignore the load upstream and we obtain the equation we must use:

$$q \approx (3)^{-1/2}\,\frac{2}{3}(2g)^{1/2} H^{3/2}$$

For the measures of the heights upstream taken, check that the flows obtained by using the latter formula and those obtained directly by the Hydraulic Bench or Group: are equal? if they aren't, which could be the reason of this difference?

Q.2 As happened with the thin-wall weirs, it is more correct to use a

formula where we have introduced a weir coefficient. The theoretical coefficient would be:

$$C_w = 3^{-1/2} = 0.577$$

and the formula recommended:

$$C_w = \frac{0.65}{(1 + H/Y)^{1/2}}$$

From the values measured of the weir upstream height and of the weir height, check the value of the coefficient.

Q.3 Calculate the flow, taking the weir as flowmeter.