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7 PRACTICAL EXERCISES MANUAL

7.1 DESCRIPTION OF THE UNIT

7.1.1 Introduction

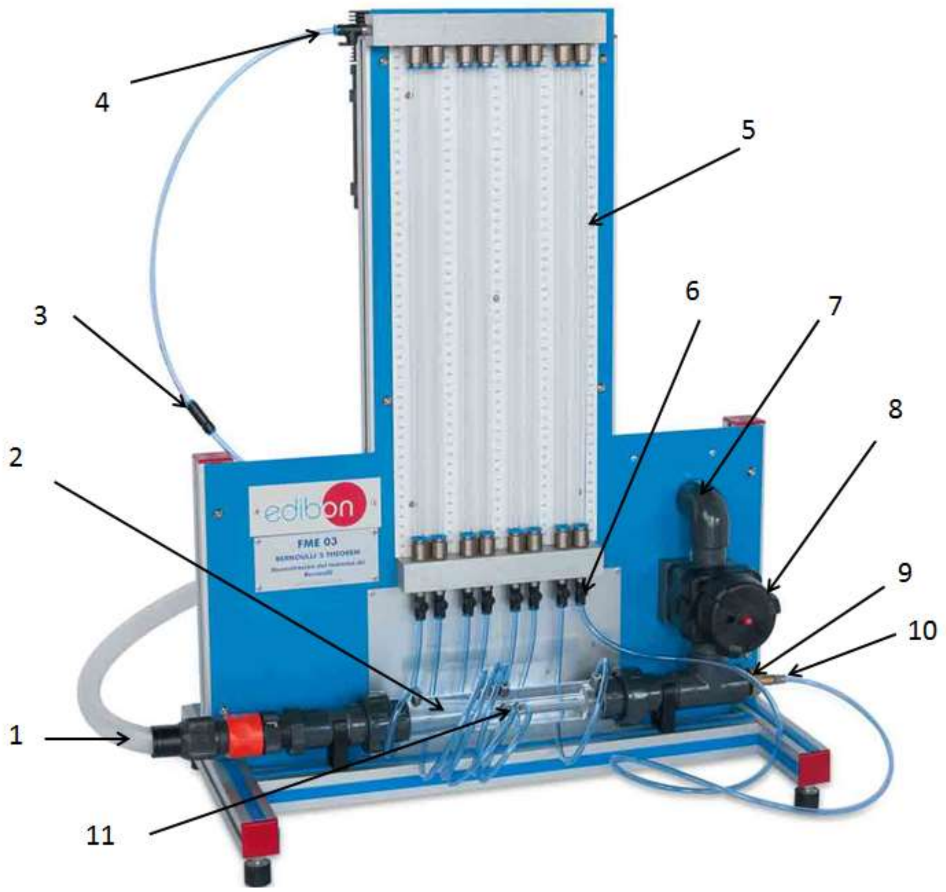
The depression generated in a constriction increases the fluid velocity and is frequently used in hydraulics, for example to manufacture machines for the supply of additives in a hydraulic pipe or in mixers.

In addition, the carburetor of an engine takes fuel by Venturi effect, mixing it with air as it passes through a constriction in the pipe.

On the other hand, the Pitot tubes applications are generally limited to large diameter pipes, with clean fluids, mainly gases and vapors. The accuracy depends on the velocity distribution and very low differential pressures are generated, being sometimes difficult to measure.

The Bernoulli's Theorem Demonstration Unit, FME03, has been designed to verify Bernouilli equation with calculations from the pressure tappings of the Venturi tube. Manometer tubes and a Pitot tube are used for the measurements. Besides, the differences of the convergent-divergent and divergent-convergent positions of the Venturi tube inside the pipe are checked.

7.1.2 Description of the unit



1. Inlet pipe to supply water to the Venturi tube.
2. Venturi tube. Transparent pipe of circular section shaped as a truncated cone with seven pressure tappings.
3. **VA-1**: check valve to drain the system.
4. **V-1**: bleed valve to regulate the head in the manometer tubes by purging the air.

5. Manometer tubes panel. It has eight tubes to read the corresponding heads required to calculate the pressure.

6. **V-2**: valves to open/close the manometer tubes. They are used to drain the manometer tubes and regulate the water head inside.

7. Outlet pipe for the water in the circuit.

8. **VR-1:** flow control valve to modify the flow rates for the experiments.

9. Knob to adjust the position of the Pitot tube in the pressure tappings.

10. Pitot tube probe connected to a manometer tube.

11. Pressure tappings of the manometer tubes.

7.1.3 Description of the process

The Bernoulli´s Theorem Demonstration Unit, FME03, is made up of a transparent pipe of circular section with the shape of a truncated cone (Venturi tube). There are seven pressure tappings along the pipe to measure, simultaneously, the static pressure values that correspond to each section with pressure tapping. All the pressure tappings are connected to a manometer tubes panel. The pressure of the manometer tubes can be regulated by introducing air in them with the aid of the air pump.

The Venturi tube is removable, so it can be located both in convergent-divergent and divergent-convergent position with respect to the stream direction.

There is also a probe (Pitot tube) that can be displaced along the pipe to measure the total pressure in the desired section.

The flow rate in the unit can be modified either by adjusting the flow control valve or by regulating the inlet supply with the valve of the Hydraulics Bench (VCC-1).

The unit has adjustable legs to keep it straightened. Besides, it can be mounted on the working surface of the hydraulics bench or the basic hydraulic feed system. Hoses are provided to supply water to the unit.

7.1.2 Practical possibilities

- Determination of the Venturi tube sections.
- Determination of Bernoulli's theorem and its limitations concerning its divergent-convergent position.
- Determination of Bernoulli's theorem and its limitations concerning its convergent-divergent position.

7.1.3 Specifications

- Manometer range: 0 - 470 mm of water.
- Number of manometer tubes: 8.
    - Bleed valve.
    - 8 open/close valves.
- Venture tube.
    - Seven pressure tappings in the Venturi tube.
    - Upstream strangulation diameter: 25 mm.
    - Angle = 10
    - Minor diameter = 10 mm
    - Largest diameter = 25 mm
    - Straight tube length = 84.5 mm

- Cone length = 85.7 mm

- Flow control valve.
- Pitot tube.
- Quick-connection system included.
- Air pump.
- Adjustable legs to straighten the unit.

7.1.4 Dimensions and weights

- Approximate dimensions: 800x450x700mm.
- Approximate weight: 15 kg.
- Approximate volume: 0.25 m^3

7.1.5 Required services

- Hydraulics Bench (FME00) or Basic Hydraulic Feed System (FME00/B).
- Chronometer (not supplied).

7.2 THEORY

7.2.1 Bernoulli equation

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

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+Z_2 \qquad [2.1.1]$$

If the pipe is horizontal, $z_1=z_2$. So the previous equation will be:

$$H=\frac{P}{\gamma}+\frac{V^2}{2g}=cte \qquad [2.1.2]$$

Where:

$\frac{V^2}{2g}$ = kinetic head.

$\frac{P}{\gamma}=h$ = piezometric head. It is the head of a water column associated with the pressure of the gravitational field.

H = total head.

In other words, Bernoulli's theorem indicates that the total head (or energy) of a fluid along a pipe is kept constant in all sections. So the total energy (E_T):

$E_T = E_S + E_k$ $\begin{cases} \text{static energy} & E_S = P_i/\gamma \\ \text{Kinetic energy} & E_K = v^2/2. \end{cases}$

This theorem considers the fluid to be ideal.

7.2.2 Graphic representation of Bernoulli's theorem

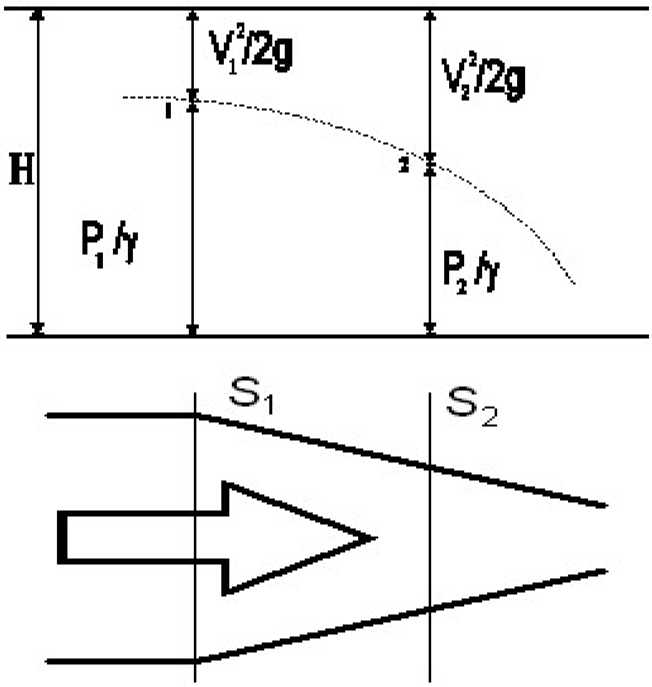


Figure 7.2.2.1

Como se observa en la figura anterior, la energía del fluido a lo largo de la tubería se mantiene constante, mientras que la energía cinética y piezométrica varían con la sección de la tubería.

These theoretical bases consider the fluid to be ideal, that is, with null viscosity. However, in fact, the velocity of the particles decreases due to friction between the particles of the fluid and the pipe. As a consequence, part of the energy of the fluid is dissipated as heat.

Considering that ΔH is the pressure drop between two sections, Bernoulli equation will be:

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+Z_2+\Delta H \qquad [2.2.1]$$

Thus, the graphic representation will be:

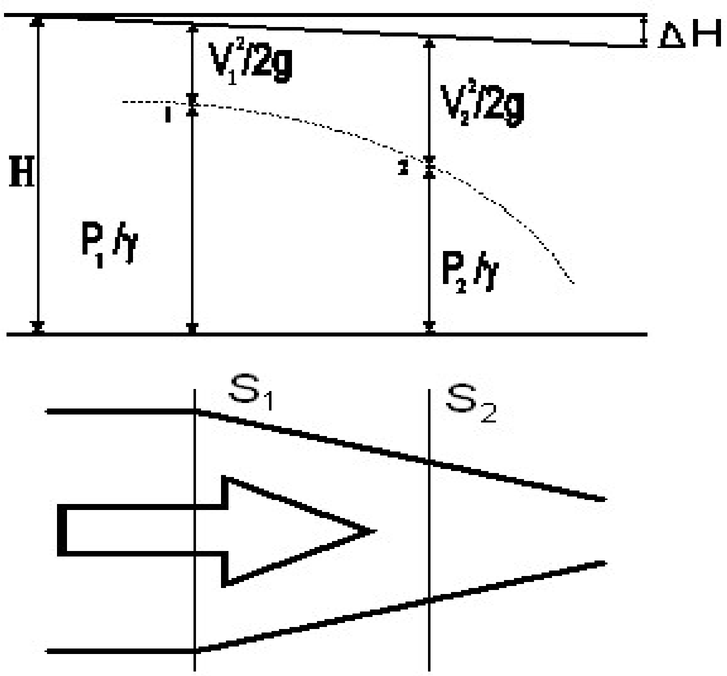


Figure 7.2.2.2

7.2.3 Pitot tubes

A Pitot tube is considered as a fixed obstacle in a flowing fluid (figure 7.2.3.1).

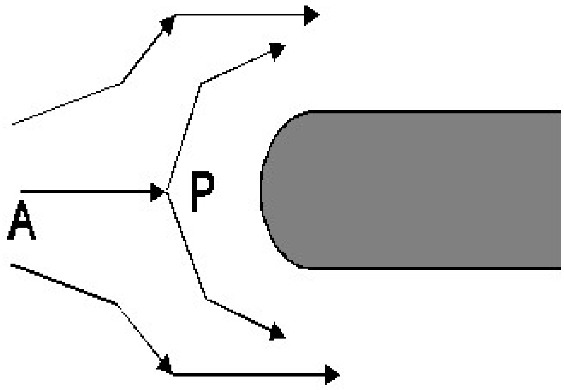


Figure 7.2.3.1

The pressure line finishes in the impact point (P). If we make an orifice in this point (P) and we connect it with a measurement tube, we are measuring the total pressure in that section (figure 7.2.2.3.).

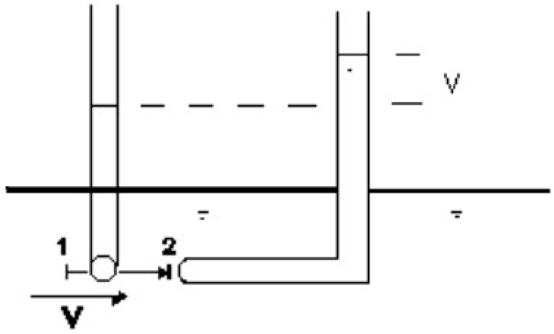


Figure 7.2.2.3

We can also know the average velocity in the pipe section:

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+\frac{V_2^2}{2g} \qquad [2.3.1]$$

$V_1 = V$ (particles velocity), $V_2 = 0$

$$\frac{V^2}{2g}=\frac{P_2-P_1}{\gamma}=\Delta h \quad \rightarrow \quad V=\sqrt{2\,g\,\Delta h} \qquad [2.3.2]$$

7.3 OPERATION

7.3.1 Filling the manometer tubes

The procedure for a correct filling of the manometer tubes is explained below.

1. Connect the water inlet and outlet tubes to the FME-03 unit.

2. Check that the flow control valve of the hydraulics bench or basic hydraulic feed system (VCC-1) and the flow control valve of the unit (VRC-1) are closed.

3. Open the VR-1 valve.

4. Start the pump with the *on/off* switch of the hydraulics bench or basic hydraulic feed system (refer to section 7.3.3) and then open slowly and fully the VCC-1 valve till the maximum flow rate is obtained.

5. Check that the valves that give access to the manometer tubes (V-2) and the bleed valve (V-1) are open.

6. After a period of time working to the maximum flow rate, close the VR-1 valve completely. The tubes will be full.

   To close the VCC-1 valve too, do it after closing VR-1 so that the manometer tubes do not empty.

7. To regulate the head of the tubes, use the check valve, VA-1. Disconnect the tube and open the bleed valve (V-1) that regulates the air inlet in the manometer tubes. Vent any possible bubble from the manometer tubes.

8. With the air pump, introduce air in the manometer tubes to pressurize the system. When there is some pressure, close the bleed valve (V-1).

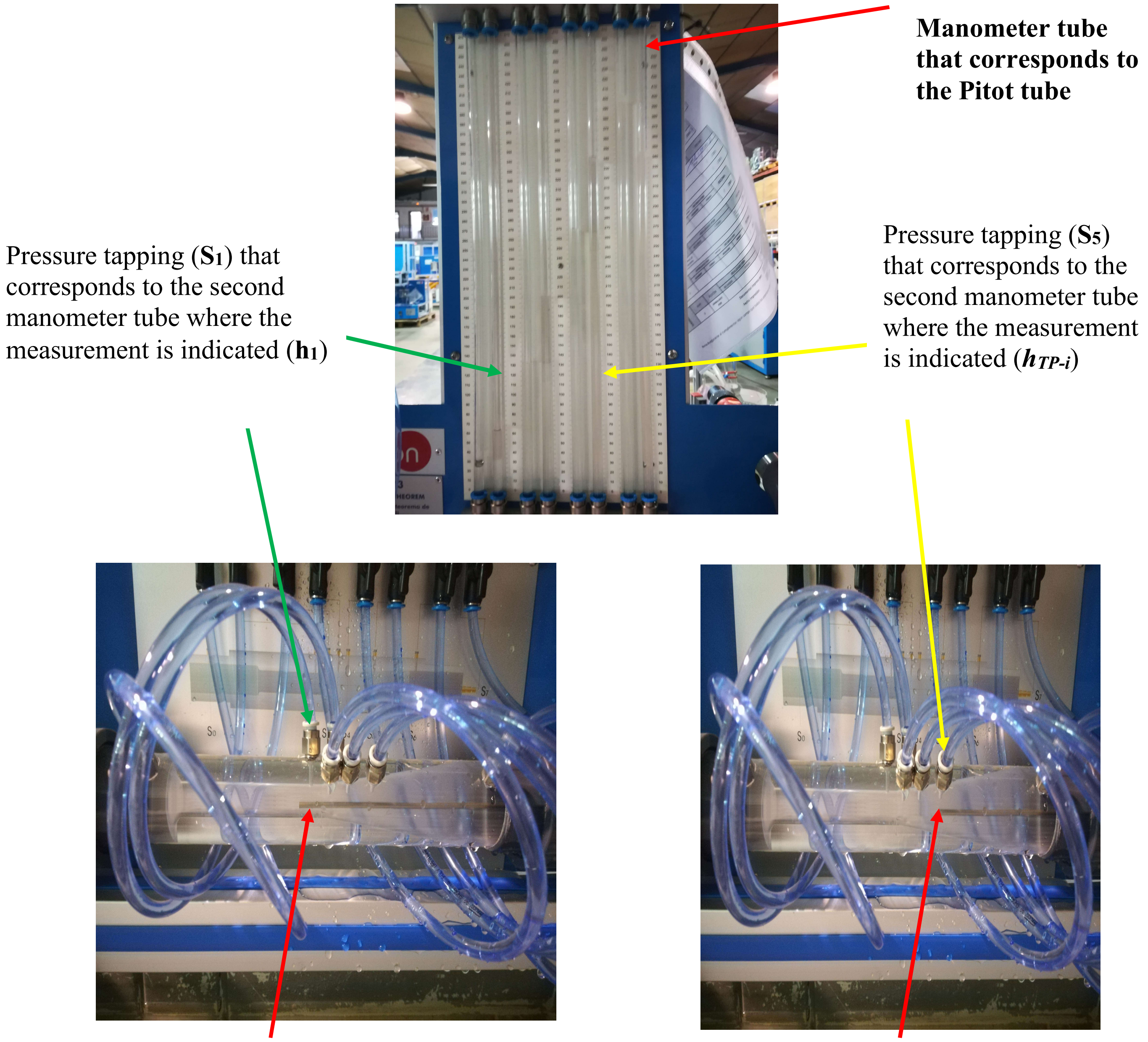
9. If you need to change the air-water level in the manometer tubes, open the VR-1 valve for a short period of time. Thus, the level in the tubes will go down.

10. Repeat this operation (6-8) till reaching in the tubes the desired head.

Important: *the last manometer tube, which corresponds to the Pitot tube, will need more time to reach the same head than the other manometer tubes.*

7.3.2 Location of the Pitot tube

The Pitot tube must be displaced during the practical exercises to locate it in different positions, as it can be observed in the following pictures:



Pitot tube (**$h_{TP\text{-}1}$**) in tapping (**S_1**)

Pitot tube (**$h_{TP\text{-}5}$**) in tapping (**S_5**)

7.3.3 Hydraulics bench (FME00)

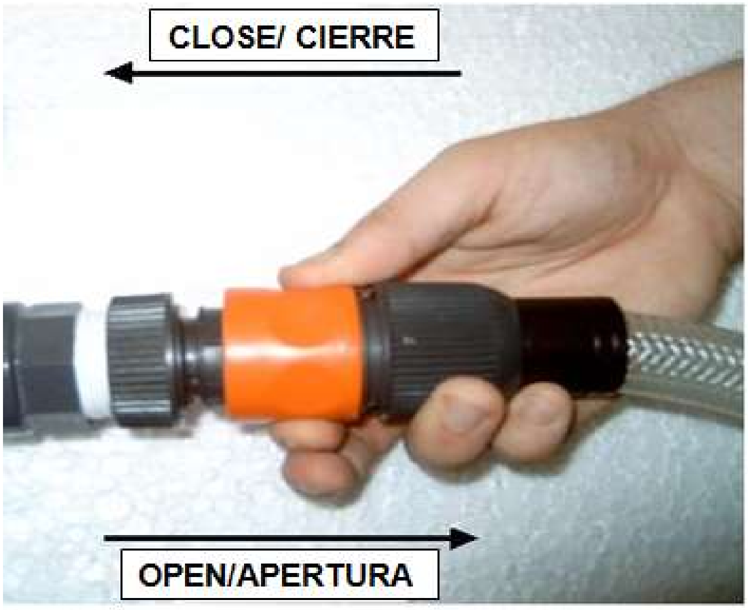
For the practical exercises performance, the Hydraulic Bench FME-00 (or the Basic Hydraulic Feed System FME-00B) is required.

The main elements of the hydraulic bench are indicated in the picture below.

The following picture shows the upper side of the FME00, where the water supply connection that is connected to the inlet of the unit can be observed.

Water supply connection

Connect the water inlet of the unit to the FME00 through the quick release fitting.



To connect the quick release fitting, apply pressure with the female end on the male end. To disconnect the tube, pull the movable part of the quick release fitting (orange color) back (follow the arrow direction), this way the quick release fitting will be easily disconnected.

Once connected, the unit must contain water to start working with it. Fill the inner tank by a side section with the hose.

7.3.4 Flow measurement with the FME00 unit

Procedure to measure the flow:

1. Check that the VCC-1 valve is open.
2. Check that the inlet and outlet connections of the unit are the right ones. In this case, the outlet hose of the unit must not be in the overflow of the lower tank of the Hydraulic Bench, but in the tank.
3. Plug the drain of the Hydraulics Bench tank with the valve or drain valve actuator provided for that purpose.
4. Switch on the pump with the ON/OFF switch (refer to the hydraulic bench picture). The tank will start to be filled and the water level will increase. Take a reference with the marks of the hydraulic bench ruler and start the chronometer at the same time.
5. Allow water to run for 1 min.
6. Using the level of the FME00 tank, measure in liters the water flowing during that minute (level difference).

   The ruler has two different sections. The first one indicates from 0 to 7 and the second one from 0 to 40. Both sections are calibrated in liters. The line of the ruler indicates the separation between the tanks. When the water reaches the 0 of the upper side, there will be 10 liters of water accumulated.

7. Determine the water flow.

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

Where:

Q: running flow (l/min)

V: accumulated volume of water (l)

t: time water is flowing between measurements (min)

7.4 MAIN INSTRUCTIONS, WARNINGS AND PRECAUTIONS

During the filling of the manometer tubes, if the VCC-1 (or VCC-2) valve needs to be closed too, do it before closing the VC2 valve.

Besides, to make water flow in the system, check that the VR-1 valve is open before opening the VCC- 1 valve.

When placing the Venturi tube, take special care with the installation of the flexible tubes. Each flexible tube from the manometer tubes must be placed in the connections in order.

During the performance of the practical exercises, observe that there are no air bubbles in the manometer tubes and none of the manometer tubes leaks air. To that end, the open/close valves of the manometer tubes must be open and the bleed valve closed.

To change the position of the Venturi tube, pull the Pitot tube out together with the knob to avoid losing the gasket of the knob.

7.5 LABORATORY PRACTICAL EXERCISES

7.5.1 Practical exercise 1: Determination of the Venturi tube exact section

7.5.1.1 Objective

The objective of this practical exercise is to obtain, with the readouts of the Pitot tube and the rest of manometer tubes, the values of the areas of the different sections of the Venturi tube.

The determination of the section in the Venturi tube allows for obtaining the pressure of the system and verifying Bernoulli equation.

7.5.1.2 Required material

- FME03 unit
- Hydraulics Bench (FME00) or Basic Hydraulic Feed System (FME 00/B)
- Stopwatch (not supplied)

7.5.1.3 Experimental procedure

1. Locate the FME03 unit on the FME00 or FME00/B unit. Follow the steps indicated in the Operation section (7.3.3 Hydraulics Bench) to know the location of the inlet and outlet of the unit.

2. The direction of the Venturi tube is not important in this practical exercise.

3. Fill all the manometer tubes as indicated in section 7.3.1.

4. Open the flow valve of the hydraulics bench or basic hydraulic feed system (VCC-1) and the control valve of the unit (VR-1).

5. Set a flow rate (Q) and record the value in table 7.3.1.3.1. Follow the procedure from section 7.3.3 to measure the flow rate.

6. Place the Pitot tube in the first pressure tapping using the wheel to move the Pitot tube. Wait until the head of the Pitot manometer tube becomes stable. This process may take 5-7 minutes.

7. When the head of the manometer tubes is stable, determine the head difference (mm) between the manometer tube of the Pitot tube and the manometer tube of the pressure tapping to which the Pitot tube has been connected.

The head of the manometer tube (right side tube) that corresponds to the Pitot tube ($\mathbf{h_{TP\text{-}i}}$) and the head of the pressure tapping ($\mathbf{h_i}$) can be recorded in table 7.3.1.3.1 and the difference between both values in table 7.3.1.3.2. The difference corresponds to the kinetic term given by "$v^2/2g$".

We consider:

- Static pressure (mm.w.c), the pressure obtained from the seven manometer tubes positioned from left to right, "h_i".

- Total pressure "h_{TP}" (mm.w.c), the pressure obtained from the right side manometer tube of the panel connected to the Pitot tube.

8. Determine the section (S) with the following equation: S = Q/v, where "Q" is the flow of water and "v" is the velocity obtained in that section. It can be calculated as follows:

$$v = \sqrt{\frac{2\,g\,(h_{TPi} - h_i\,)}{\rho}} \qquad (m/s)$$

Where g is the gravitational constant (9.81 m/s^2) and ρ = 1000 kg/m^2.

Record the velocity in table 7.3.1.3.2.

9. Repeat steps from 6 to 8 with each pressure tapping (7 in total).

10. Repeat steps from 5 to 9 with different flow rates.

7.5.1.4 Worksheet

Student: ____________________ Year: __________

Complete the tables.

Calculate the average of the sections obtained with different flows of water. *The section must be more or less the same for each flow of water (flow rates of 5 l/min, 10 l/min and 15 l/min are recommended for this practical exercise).*

Table: Experimental data

Position: indicates the pressure tappings along the Venturi tube. Besides, each number corresponds to the tappings indicated in the diagram attached to the frame of the unit.
h_{TP-i}: head of the manometer tube that corresponds to the Pitot tube.
h_i: head of the manometer tube that corresponds to the different sections of the Venturi tube ("i" represents: 1, 2, 3…6).

Position	Q_1 (L/min)		Q_2 (L/min)		Q_3 (L/min)	
	h_{TP-i} (m.w.c)	h_i (m.w.c)	h_{TP-i} (m.w.c)	h_i (m.w.c)	h_{TP-i} (m.w.c)	h_i (m.w.c)
0						
1						
2						
3						
4						
5						
6						

Table 7.3.1.3.1

Table: Calculations

	Q_1			Q_2			Q_3			
Pos.	$h_{TP\text{-}i} - h_i$	v_1 (m/s)	S_1 (m)	$h_{TP\text{-}i} - h_i$	v_2 (m/s)	S_2 (m)	$h_{TP\text{-}i} - h_i$	v_3 (m/s)	S_3 (m)	$S_{average}$
0										
1										
2										
3										
4										
5										
6										

Table 7.3.1.3.2

Q.1. Which is the reason of the difference between S_1, S_2 and S_3?

____

Q.2. Why does the pressure measured by the Pitot tube decrease along the pipe?

____

7.5.2 Practical exercise 2: Demonstration of Bernoulli´s theorem. Divergent-convergent position

7.5.2.1 Objective

The objective of this practical exercise is to demonstrate Bernoulli's theorem and to find its limitations in real fluids.

To that end, the Venturi tube is used in divergent-convergent position and the energy is calculated in that arrangement to check that it is constant. To obtain the required data, the static pressure is measured by the head of the water column and the kinetic energy is measured by the head difference between the Pitot manometer (total pressure) and the manometer of the section in question (static pressure).

7.5.2.2 Required material

- FME03 unit
- Hydraulics Bench (FME 00) or Basic Hydraulic Feed System (FME00/B)
- Stopwatch (not supplied)

7.5.2.3 Experimental procedure

1. Locate the FME03 unit on the FME00 or FME00/B unit. Follow the steps indicated in the Operation section (7.3.3 Hydraulics Bench) to know the location of the inlet and outlet of the unit.

2. The direction of the Venturi tube is not important in this practical exercise.

3. Fill all the manometer tubes as indicated in section 7.3.1.

4. Open the flow valve of the hydraulics bench or basic hydraulic feed system (VCC-1) and the control valve of the unit (VR-1).

5. Set a flow rate (Q) and record the value in table 7.3.1.3.1. Follow the procedure from section 7.3.3 to measure the flow rate.

6. Place the Pitot tube in the first pressure tapping using the wheel to move the Pitot tube. Wait until the head of the Pitot manometer tube becomes stable. This process may take 5-7 minutes.

7. When the head of the manometer tubes is stable, determine the head difference (mm) between the manometer tube of the Pitot tube and the manometer tube of the pressure tapping to which the Pitot tube has been connected.

The head of the manometer tube (right side tube) that corresponds to the Pitot tube (**h_{TP-i}**) and the head of the pressure tapping (**h_i**) can be recorded in table 7.3.1.3.1 and the difference between both values in table 7.3.1.3.2. The difference corresponds to the kinetic term given by "$v^2/2g$".

We consider:

- Static pressure (mm.w.c), the pressure obtained from the seven manometer tubes positioned from left to right, "h_i".

- Total pressure "h_{TP}" (mm.w.c), the pressure obtained from the right side manometer tube of the panel connected to the Pitot tube.

8. Determine the section (S) with the following equation: S=Q/v, where "Q" is the water flow and "v" is the velocity obtained in that section. It can be calculated as follows:

$$v = \sqrt{\frac{2\ g\ (h_{TPi} - h_i\ )}{\rho}} \qquad (m/s)$$

   Where g is the gravitational constant (9.81 m/s^2) and ρ=1000 kg/m^2.

   Record the velocity in table 7.3.1.3.2.

9. Repeat the steps from 6 to 8 for each pressure tapping (7 in total).

10. Repeat the steps from 5 to 9 for different water flows.

Important: the values of the sections (S) obtained in the practical exercise 1 can be used in this practical exercise.

11. When you have the head values (h_{TP} and h_i) indicated by the manometers and the value of S, calculate the value of the kinetic head from the value of a Q and the values of the sections. Follow this expression:

$$\boldsymbol{h\ (kinetic\ head) = \frac{Q^2}{2\ g\ s^2}\ (m)}$$

12. The piezometric head can be obtained as follows:

$$\boldsymbol{h}\ (\boldsymbol{piezometric\ head}) = \frac{\boldsymbol{h_i}}{\boldsymbol{\rho\ g}} \quad \textbf{\textit{(m)}}$$

13. The total head can be obtained from the formula below:

$$\boldsymbol{h}\ (\boldsymbol{total\ head}) = \frac{\boldsymbol{h_{TPi}}}{\boldsymbol{\rho\ g}} \quad \textbf{\textit{(m)}}$$

7.5.2.4 Worksheet

Record in the following table the obtained data.

Determine the velocity of the fluid and the kinetic head for each position.

Determine the total theoretical head by adding the theoretical kinetic head and the measured static head.

Flow rate (m^3/s)	Section* (m^2)	Average velocity (m/s)	Kinetic head (m)	Piezometric head (experimental information) (m)	Total head kin.+Piez. (m)	$h_{(Pitot)}$ (m)

Table 7.3.2.3.1

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

Q.1. Do these total heads coincide with the total heads measured with the probe?

If they are different, explain why.

Q.2. Comment the validity of Bernoulli equation for:

a) Convergent flow (practical exercise 2)

b) Divergent flow (practical exercise 3)

7.5.3 Practical exercise 3: Demonstration of Bernoulli´s theorem. Convergent-divergent position

Repeat the previous practical exercise. In this case, change the position of the Venturi tube to study the phenomenon in the convergent-divergent direction.