Properties of Fluids

1. Introduction

In this laboratory session we will study some of the properties of fluids. In the first part, we will experience the effect caused by the buoyance force when a solid body, which is initially suspended in the air, is completely submerged in water and we will measure the density of the material that constitutes the solid. In the second part, we will study the behavior of moving fluids, with the help of a simulation.

2. Buoyance force and calculation of the density of a material

In order to study the bouyance force on a solid body of mass *m* completely submerged in water, we hang it with a thread of negligible mass on a dynamometer. The measurement reading in the dynamometer corresponds to the weight of the body. That is, the force measured by the dynamometer is given by

$$F_1 = P = m\,g \tag{1}$$

where *g* represents the acceleration of gravity. If the volume of the body is *V*, and its density ρ, then this force can be expressed as

$$F_1 = \rho V\, g \tag{2}$$

If now, without removing the body from the dynamometer, we introduce the body inside a container with water so that we submerge it completely, the dynamometer reading changes as a result of a pushing force on the body, equal to the weight of the water dislodged by it. This force acts in the opposite direction to the force of the weight. Thus, the new force measured by the dynamometer will be

$$F_2 = P - E = \rho V g - \rho_o V g = V g(\rho - \rho_o) \tag{3}$$

where ρ_o represents the density of water. Combining the equations that the dynamometer readings give us before and after submerging the solid, we get

$$F_2 = \left(1 - \frac{\rho_o}{\rho}\right) F_1 \tag{4}$$

Considering that $\rho_e = \rho / \rho_o$ is the specific density of the submerged solid (relative density of the solid with respect to that of water), we can finally write

$$F_2 = \left(1 - \frac{1}{\rho_e}\right) F_1 \tag{5}$$

So if we have different solid pieces of the same material and, for each piece, we write down the corresponding dynamometer readings, before (F1) and after (F2) to immerse it in water, we can obtain the specific density ρ_e. To find the result we will perform a linear adjustment,

$$F_2 = bF_1 \tag{6}$$

which will give us the value of the slope b, from which we can calculate ρ_e,

$$\rho_e = \left(\frac{1}{1-b}\right) \tag{7}$$

and, therefore, we can obtain the density of the solid ρ.

3. Bernoulli Equation

Bernoulli's equation expresses the conservation of energy in a moving fluid when there is a variation in height from a reference point and the fluid is incompressible, stationary and laminar flow, and viscosity can be neglected. This equation states that for a fluid of density ρ, the relationship between pressure P, velocity v and height h at two different points, 1 and 2, is as follows:

$$P_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2 \tag{8}$$

4. Experimental procedure

First Section: measurement of the density of a solid

The material required for the first part of the experiments is as follows:
- Dynamometer
- Beaker
- Thermometer
- Holders and wire/thread
- A set of metallic weights, each piece of the same material but with different weight, we will know the density of the material.

Follow this procedure:

a) Suspend a part of the solid on the dynamometer using a wire/thread of negligible mass and write down the force F1 recorded by the dynamometer.

b) Then, without picking up the dynamometer part and using a beaker filled with distilled water, the support that holds the dynamometer is lowered until the part is completely submerged in the water. Write down the reading of the dynamometer which corresponds with force F2. With a thermometer measure the temperature of the distilled water.

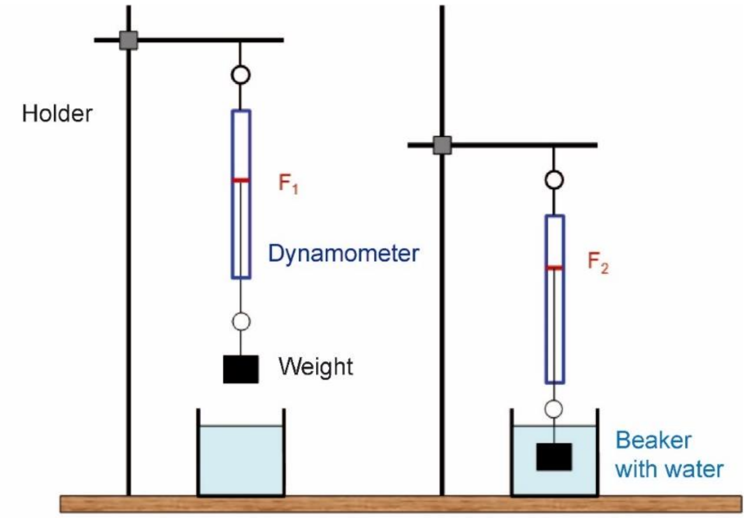

Fig. 1.Diagraman of the experimental set-up to study the density of a solid material.

c) Repeat the previous measurements with the rest of the pieces and determine for each of them the specific density. Calculate the slope *b* with the linear adjustment and then calculate the experimental value of the specific density (ρ_e) and the density of the material (ρ) from which the pieces are made.

d) Calculate the absolute density of the material. First, using the following table that provides the values of the density of the distilled water at different temperatures, obtain the value of the density of the distilled water used, at the laboratory temperature (interpolating the value if necessary). From this value and the specific density obtain, with its uncertainty, the density of the material from which the metal parts are made.

T (ºC)	0	5	10	15	20	25	30
ρ (g/cm³)		0,9999	0,9997	0,9989	0,9982	0,9969	0,9957
η (cp)	1,7865	1,5138	1,3037	1,1369	1,0019	0,8909	0,7982
σ (din/cm)	75,7	75,0	74,2	73,5	72,5	72,0	71,2

e) Save the excel spreadsheet with all the information needed to carry out the calculations requested in the handout section (i.e. linear regressions, slope values, interpolation values,….*).*

Second section: use of a simulation tool

https://phet.colorado.edu/en/simulation/fluid-pressure-and-flow and consider the following instructions:

a) **Parabolic movement:** In the "Water tower" tab, fill the water tank, connect the hose and when the hose is at ground level orient it with a given angle. You can adjust the water intake to the amount lost (Match leakage). Measure the water velocity vector at the outlet of the hose (the velocity module is determined with one of the available velocity sensors and the orientation with the measuring tape that can measure the angle from length measurements).

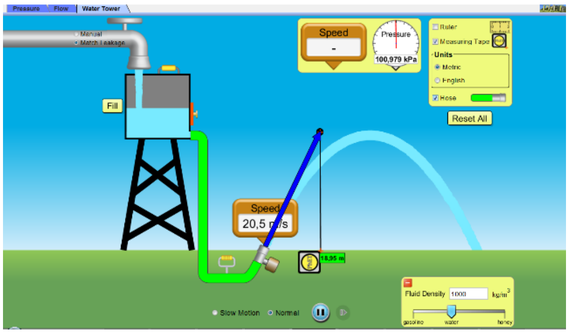

Fig. 2. Diagram to calculate maximum height and horizontal range.

Apply the kinematic equations as if it were a parabolic shot to calculate the maximum height and horizontal range and verify that the calculated values correspond to those measured in the simulation.

b) **Pressure:** To check the relationship $\Delta P = \rho g \Delta h$, close the water outlet of the tank, and place a pressure sensor at the base of the water volume and another at the top (this will measure the atmospheric pressure). Take into account the density of the simulated fluid, and as the tank is filled (you can stop the simulation or delay it) take the height difference between the top and bottom point of the water volume five times, to check that on each of they meet the relationship $\Delta P = \rho g \Delta h$.

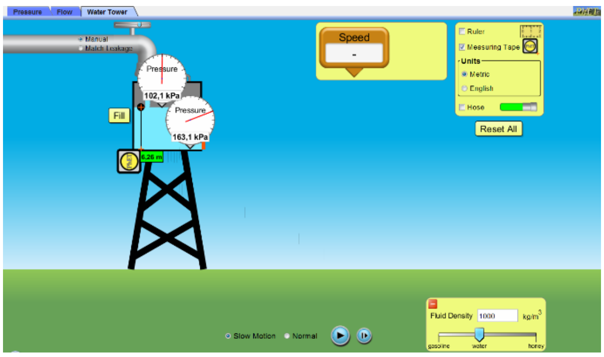

Fig. 3. Diagram to measure differences in pressures.

c) **Speed at exit of the fluid of a tank and range of horizontal reach:** Now, while the tank is emptying (closes the entrance and opens the exit tap), at six different times, measure the speed at the exit with a sensor, and measure the range horizontal. To check the data, you must know the height of the volume of water stored at each moment and the height of the tower, *H*. In this case, the speed at the exit of the tank from Bernoulli's equation is expressed as $v = \sqrt{2g(h_2 - h_1)}$. If we consider that the pressure at the lower and upper points is the atmospheric one, and that since the outlet has a small diameter, the lowering speed of the tank is negligible. With respect to the horizontal reach of the jet of exit, if we consider that the horizontal and vertical positions are given by $x = vt,\ \ y = H - gt^2/2$, and the for the position y = 0, $t = \sqrt{2H/g}$, we conclude that $x = v\sqrt{2H/g}$.

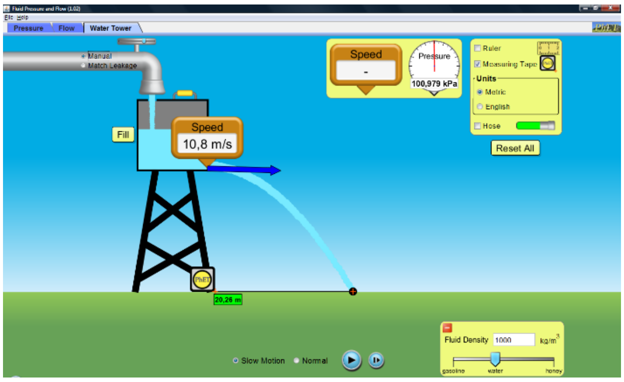

Fig. 4. Diagram to measure velocity and horizontal range at the exit of the tank.

You can also explore the other tabs of the simulation: "Flow" and "Pressure".

- Please, save the calculated data on a Word file with your name and surname in the file name. Include the following results:

4. Hand out of results

a) Fill your lab book with all the information calculated during the session: 1-Calculated values of *b*, T, ρ_0, ρ_e and ρ and 2- Table comparing data obtained in the simulation tool and that calculated from kinematics equations for each of the subsections. The lab book must contain the following sections: introduction, experimental, results and discussion and conclusions as explained in the first laboratory session.