Archimedes' Principle

OBJECTIVE

- to confirm Archimedes' Principle for objects of different densities ($\rho_{\text{object}} > \rho_{\text{fluid}}$) and ($\rho_{\text{object}} < \rho_{\text{fluid}}$)

- to determine the density of unknown materials using Archimedes' Principle

EQUIPMENT

force sensor

a beaker

electronic balance

string

masking tape

overflow can

catch can

different objects (wood cube, rubber stopper, golf ball)

water

rods and base

GA software

INTRODUCTION AND THEORY

When an object is immersed in a fluid, it feels lighter than when it is in the air. The surrounding fluid presses against the object from all directions. The sideways forces would be balanced and oppose each other equally. The upward and downward forces would not be the same because the fluid pressure increases with the depth. In fluid, the pressure at the bottom of the object will be greater than the pressure at the top of the object due to the weight of the layers of fluid between the top and bottom part of the object.
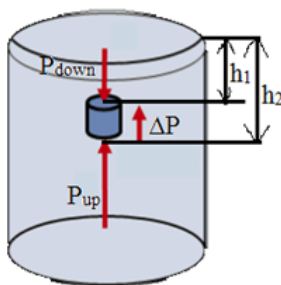

Figure 1

The gauge pressure (ΔP) is given by the following equations.

$$\Delta P = P_{\text{down}} - P_{\text{up}} \tag{1}$$

$$\Delta P = \rho_f \, g(h_2 - h_1) \tag{2}$$

The gauge pressure is a function of depth, h. The unit of pressure is Pascal (Pa).

As a result of the pressure difference, there is an upward buoyant force, F_b, that acts on the fully or partially submerged object (fig. 2).
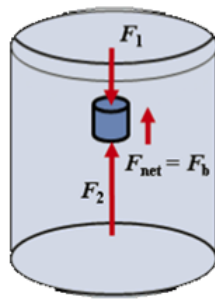

Figure 2

In the special case of an object such as a cylinder oriented flat side down, the buoyant force equals the product of the gauge pressure and the top surface area.

$$F_b = \Delta P A \tag{3}$$

$$F_b = \rho_f \, g(h_2 - h_1)A \tag{4}$$

Considering that $(h_2 - h_1) = h$ is the height of the submerged cylinder, we get $hA = V_o$. Hence, the buoyant force can be found using the following equation:

$$F_b = \rho_f \, gV_o, \tag{5}$$

where ρ_f is the density of fluid (kg/m^3) and V_o is the volume of the submerged part of the object (m^3). The buoyant force depends on the density of the liquid and the volume of the object submerged into the fluid, but not its weight or shape.

If the density of the object is greater than that of the fluid, the object will sink. If the density of the object is equal to that of the fluid, the object will neither sink nor float. If the density of the object is less than that of the fluid, the object will float.

When the object is placed into the fluid, the fluid gets displaced. The displaced fluid has weight:

$$W_f = m_f \ g, \tag{6}$$

where m_f is the mass of the displaced fluid. The mass, m_f, of the fluid can be expressed in terms of its density, ρ_f, and volume, V_f:

$$m_f = \rho_f \ V_f. \tag{7}$$

Hence,

$$W_f = \rho_f \ gV_f = f_b. \tag{8}$$

Eqn. (8) expresses **Archimedes' Principle**.

> **Archimedes' Principle:** Any object, wholly or partly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

From this principle, we can see that whether an object floats or sinks in water is not based on its own weight, but the amount of water it displaces. That is why a very heavy ocean liner can float. It displaces a large amount of water.

The weight of the object submerged into the fluid is called apparent weight, W_{apr}, and it is equal to the difference between the weight of the object in the air, W_o, and the buoyant force, F_b.

$$W_{\mathrm{apr}} = W_o - F_b \tag{9}$$

PROCEDURE

Please print the worksheet for this lab. You will need this sheet to record your data.

Part 1. Archimedes' Principle

1 Place the force sensor on the horizontal rod. In order for the sensor to work properly it has to be calibrated. Open the DataStudio$^{®}$ Program: Labs/PreSetUp Labs/Fluid Mechanics.

Force Sensor Calibration Procedure

1 In the DataStudio® program, open "Setup", put a check mark next to the "Force sensor" as a sensor connected to channel A. Choose "Calibrate Sensor", then "2-Point Calibration".

2 With nothing hanging from the sensor, set the first value to be zero, then press the "Tare" button on the force sensor itself, and finally select "Read from Sensor" in DataStudio®. The "Tare" button sets up a zero on the force sensor.

3 To setup a second value, put a 1.00 kg mass to hang from the sensor. Set the second value of calibration point in DataStudio® to 9.81N and select "Read from Sensor".

4 Click "Ok". Close the setup window.

5 Check your calibration by taking 5 seconds of data with the 1.00 kg mass hanging from the sensor. If you see a horizontal line (a line with a zero slope) drawn at a 9.81 N-level, the force sensor is calibrated and ready to take measurements of the force.

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2 Measure the mass of the empty catch can. The catch can will be used to collect water displaced by the submerged object. Record the mass on the Lab 11 worksheet.

3 Place the overflow can under the force sensor. Place a 250-mL beaker under the angled overflow spout. Fill the overflow can with room temperature tap water just above the spout, until it begins to overflow. Wait for the dripping from the overflow spout to stop. Remove the 250-mL beaker and replace the catch can under the overflow spout.

4 **Zero/"Tare" the Force Sensor**. Use a string to suspend the rubber stopper ($\rho_{\text{object}} > \rho_{\text{fluid}}$) from the Force Sensor. Position the object slightly above the water surface in the overflow can.

5 Click **Start**. If there is some fluctuation in the data, wait for the data to become more stable. Record the mean value of the weight of the object in the air in Table 1 on the Lab 11 worksheet. (Hint: Select the part of the graph where the force seems to be constant, then choose statistics from the menu bar).

6 Leave DataStudio® in the recording mode. Slowly move down a rod with a force sensor to fully submerge the rubber stopper in the water. Wait until the dripping from the overflow can stops. Record the mean value of the apparent weight of the rubber stopper in Table 1.

7 Measure the mass of the graduated cylinder with the displaced water. Record the mass of the graduated cylinder and displaced water in Table 1. Also measure the volume of the water in the graduated cylinder. Record this value in Table 1.

8 In the Lab Report, you will use the data you collected to calculate the weight of the displaced water, eqn. (6), to calculate the magnitude of the buoyant force twice, first using eqn. (5) and then using eqn. (9), and then to find the percentage differences between the weight of the displaced water and the magnitude of the buoyant force in each case.

9 Dump the water from the beaker, and then dry the beaker with the paper tower. Remove the object from the force sensor.

10 Replace the object with the second provided object ($\rho_{\text{object}} < \rho_{\text{fluid}}$). Repeat steps 3-9. Both sets of experimental data will be used in the Lab Report to prove Archimedes' Principle.

Part 2. Determine the density of the golf ball

1 Measure the mass of a golf ball with an electronic balance. Record the mass in Table 2 on the Lab 11 worksheet. You will submerge the object into the catch can.

2 Use the same procedure from the previous part to measure the weight of the object in the air and its apparent weight after submerging the object under the water in the catch can. Record the mean value of both forces in Table 2.

3 In the Lab Report, you will need to find the density of the object using the density equation and Archimedes' Principle. (Hint: Combine equations (9) and (5) to find the volume of the water displaced by the object. The volume of the displaced water equals the volume of the object).

4 The theoretical value of the golf ball density is 1130 kg/m^3. In the Lab Report, you will need to find the percent discrepancy between the theoretical and experimental values of the golf ball's density.

Part 3. What is the mass?

1 Pour 200 mL water into a beaker.

2 Place the beaker with water on the electronic balance, and then measure their total mass and record in Table 3.

3 Predict what will be the reading on the balance if you immerse the golf ball of a known mass into the water (no water overflow from the beaker).

4 Go ahead and try it. Does the result match your prediction?

5 In the Lab Report, explain the meaning of the result shown by the electronic balance. Explain the reason for any discrepancy between your predicted and experimental result.

DISCUSSION

Start your discussion with the statement of the purpose of the lab experiment, and then provide a brief theoretical explanation about your expected results. Report the experimental results that you found in this lab. The answers to the following questions need to be a part of your discussion section.

Do your experimental results support Archimedes' Principle? Support your answer with evidence. What was the major reason for any type of error in this experiment? What does the apparent weight mean?

King Hiero was worried that the metalist who was making him a golden crown was replacing some of the gold with another metal. King Hiero called upon Archimedes to find a way to see if the crown was made of pure gold or a combination of metals. How would you solve the famous Archimedes' crown problem based on the knowledge of the Archimedes' Principle?

Could there be any truth to the statement that it is easier to float in salty ocean water than in fresh water? Support your answer with evidence.

Was the prediction of the mass in Part 3 correct? Explain what made you make the correct/incorrect statement.

What are the reasons for any high discrepancy in this lab? How can it be reduced in the experiment?

CONCLUSION

Provide a clear statement if the objective of the Lab "Archimedes' Principle" is met. Support all your answers with evidence.