2.5 Fluid Mechanics

Summary

Students are introduced to Bernoulli's Equation and use a simplified version to perform hydrostatic pressure and flow rate calculations.

Learning Objectives

After this class, students will be able to:
- Calculate pressure as a function of water tower height.
- Calculate velocity and volumetric flow rate as a function of height.
- Identify differences between real flow and frictionless flow situations.
- Identify the two purposes of a water tower.

Materials

- Each student will need the Fluid Mechanics Exercises worksheet, a pencil and a calculator.

Time

80 minutes

Procedure/Pacing

1. Ask class to give examples of how pressure changes with depth of a fluid. (Swimming, ears popping when going up and down hill, etc.)
2. Most municipal water systems are supplied by water towers. Why do communities use water towers?
   a. Consistent source of water even during power or pump outages.
   b. Need only size a pump to meet average demand, and not peak demand.
3. Explain that students will be building and testing their own water supply network in the next lab. First, it is necessary to get a feel for what is happening within the network.
4. First we need to understand how depth in a fluid (or height of a water tower) affects the pressure in a fluid.

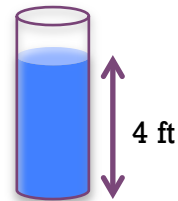Example Calculation of Pressure in a Fluid:
Calculate the pressure acting at 4 feet below the surface in a column of water.
Things to know before we begin:

ρ = fluid density = 1.94 slugs/ft^3 for H_2O at 32 °F.
1 slug = 1 lb$_f$/(1 ft/s^2), where lb$_f$ is pound-force, the force unit in the British unit system
g = 32.17 ft/s^2

4 ft

$$1 \text{ ft}^2 = 144 \text{ in}^2$$

Begin by using the fluid statics equation

$$\Delta P = P - P_{atm} = P_{guage} = \rho g h$$

$= (4 \text{ ft}) (1.940 \text{ slugs/ft}^3) (32.174 \text{ ft/s}^2)$

$= \underline{249.7} \text{ lb}_f/\text{ft}^2 \text{ (psf)}$

$= \underline{1.7} \text{ lb}_f/\text{in}^2 \text{ (psig, or guage pressure)}$

P = Pguage + Patm = <u>16.4</u> psia (absolute pressure)

5. Have class work Problem 1 from the worksheet. Students may discuss problem with nearest neighbor. Discuss as a class to clear up any misunderstandings.
6. Have class work Problems 2 and 3. Have students try to discuss the problems with a new neighbor.
7. Discuss findings as a class. What is the overall relationship between pressure and depth? Static pressure increases with increased depth.
8. Ask: "How does this pressure depend on the shape of the tank or piping?"
   Answer: It does not depend on shape of tank or piping?
9. Ask: "How does pressure depend on path?"
   Answer: It does not depend on path.
10. Explain that pressure is the driving force behind the flow rate in pipes. Explain that students have just performed calculations for a situation in which no water is flowing. Now students will calculate what happens when a faucet is turned on, or a valve is opened and water flows through the pipes.

Example Calculation of Velocity of Fluid Flowing From a Tank:
Calculate the velocity at which the water would flow if a ½ inch diameter hole were punched in the bottom of the tank of the previous example.
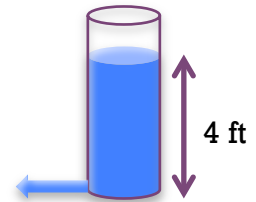

4 ft

Begin by using the simplification of Bernouli's Equation

$$v = \sqrt{2gh}$$

v = (2 * 32.174 ft/s² * 4 ft)^½

   = <u>16</u> ft/s

To calculate the volumetric flow rate, Q, simply multiply the velocity by the area through which the water is flowing.

Q = v*A

   = 16 ft/s * 3.14159 * (0.5 in (1 ft/ 12 in.))²

   = <u>0.087</u> ft³/s = <u>0.65</u> gal/s

11. If possible, have students switch seats. Have class work Problems 4 and 5. Discuss with neighbor.

12. Discuss findings from the flow rate calculation problems. Flow rates decrease with height.
13. Help students understand that we have been using assumptions of idealized flow. Discuss differences for real flow situations. In real flow, friction comes into play. There is friction between the fluid and the pipe through which it is flowing. The flow rate of the fluid, the diameter and composition of the pipe, pipe fittings, and curves or bends all affect the pressure drop due to friction.

In-Class Assignment
Assignment 2.5i: Fluid Mechanics Exercises

Resources
Hydrostatic Pressure
- https://www.khanacademy.org/science/physics/fluids/density-and-pressure/a/pressure-article
- http://faculty.wwu.edu/vawter/PhysicsNet/Topics/Pressure/HydroStatic.html

Bernoulli's Equation
- http://www.aplusphysics.com/courses/honors/fluids/Bernoulli.html
- https://ecourses.ou.edu/cgi-bin/ebook.cgi?doc=&topic=fl&chap_sec=07.1&page=theory
- http://www.4physics.com/phy_demo/bernoulli-effect-equation.html

Homework
Assignment 2.6h: Water Town Introduction and Design of Experiments