

# Fluids: How thick are liquids?

## Student Advanced Version

### Introduction:

**Fluids** are substances that can flow under an applied force. What are some examples of fluids? We often think of fluids as substances that are in the liquid phase. For example, water is a fluid. When we pour water into a glass, it conforms to the shape of the glass. Gases do this too. They are fluids because they can flow and deform in response to an applied stress or force.

*Q1. Are the following items below fluids (Indicate yes or no in the space provided)?*



*Cheese* \_\_\_\_\_



*Air* \_\_\_\_\_



*Water* \_\_\_\_\_



*Toothpaste* \_\_\_\_\_

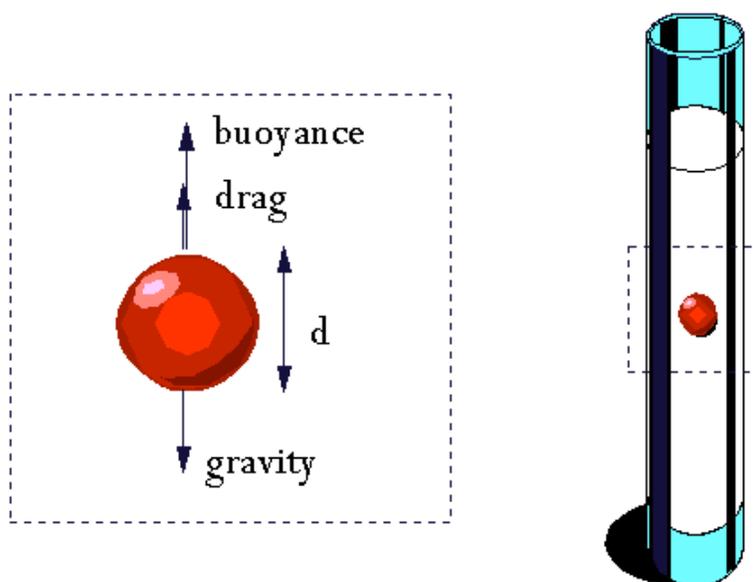
## Part I – Viscosity

### Key Concepts:

- **Viscosity** tells us the resistance of a fluid on which a force is acting.
- For fluids, it basically refers to how ‘thick’ a fluid is.

### Objective:

In this experiment, we will drop spherical balls of clay into three fluids and calculate the viscosities of the fluids by measuring the velocities of the balls as they fall. Three forces act on a spherical ball of clay falling through a fluid: gravity, drag, and buoyancy. We will discuss drag in more detail in the next experiment:



**Gravity** is simply the mass of the sphere ( $m$ ) multiplied by the gravitational constant  $g$ . It is the weight of the sphere.

$$Gravity = mg$$

**Buoyancy ( $F_b$ )** is essentially the weight of fluid that is displaced by the sphere. You can think of it as the weight of a spherical ball of the fluid. Thus, it is calculated by taking the mass of the fluid that would fill that sphere multiplied by the gravitational constant  $g$ . We can calculate the mass using the volume of the sphere, which is  $(4/3)\pi r^3$  where  $r$ =radius, and the density of the liquid ( $\rho_{fluid}$ ).

$$F_b = (4/3)\pi r^3 \rho_{fluid} g$$

The **drag force** is given by Stoke’s Law. This law only applies for spherical objects in fluids that are flowing in a steady manner (not turbulent). Drag opposes the downward gravitational force and is dependent on the viscosity of the fluid ( $\mu$ ), the size of the sphere ( $d$ =diameter), and the sphere’s velocity ( $V$ ) as it falls through the fluid.

$$F_d = 6\pi\mu Vd$$

Assuming the sphere is falling at a constant velocity in a calm fluid, we can say that the sum of the forces pointing upwards is equal to the sum of the forces pointing downwards to get the following equation that will allow us to calculate viscosities of fluids.

$$F_b + F_d = mg$$

$$\left(\frac{4}{3}\right)\pi r^3 \rho_{fluid} g + 6\pi\mu Vd = m_{sphere} g$$

**Procedure:**

- 1) Fill three 100 mL graduated cylinders (or tall clear cups) with three different fluids: water, vegetable oil, handwashing soap. The densities of these three fluids are as follows:  
 $\rho_{water} = 1 \text{ g/mL}$        $\rho_{vegetable \text{ oil}} = 0.894 \text{ g/mL}$        $\rho_{hand \text{ soap}} = 0.932 \text{ g/mL}$   
 Note: 1 mL = 1 cm<sup>3</sup>
- 2) Measure the height of the fluid in each glass using a ruler and note down the mass of each block of clay from the package.
- 3) Mold each block into a sphere and measure the diameter of the sphere using a ruler. You may splice the sphere into half using a knife to more accurately measure the diameter.
- 4) Drop individual balls into graduated cylinders at the same time. Start the stopwatch.
- 5) Record the times it takes for the ball to hit the bottom of the glass in each liquid and calculate the velocities of each ball in each liquid based upon the height of the liquid and the time.

Liquid	Time (s)	Velocity (cm/s)
Water		
Vegetable Oil		
Hand Soap		

*Q2. Rank the viscosities of honey, soap, water, and oil. Which one is the most viscous or can resist flow most effectively?*

*Q3. Which ball took the longest amount of time to reach the bottom of the glass?*

*Q4. Based on these results, what can we say qualitatively about the viscosities of the three liquids? Rank them from most to least viscous.*

6) Now let's actually calculate the viscosities of the three liquids using the formula from above. Use  $g = 9.8 \text{ m/s}^2$ .

Remember:  $(4/3)\pi r^3 \rho_{\text{fluid}} g + 6\pi\mu Vd = m_{\text{sphere}} g$

***Water:***

***Vegetable Oil:***

***Hand Soap:***

*Q5. What effect do you think temperature has on viscosity? (Think about maple syrup!)*

## Part II – Drag

### Key Concepts:

- **Drag** measures the forces that oppose the motion of an object through a fluid.
- The lower the drag on an object the faster it travels through a fluid.

*Q6. Why do you think skiers bend over when they ski? How about cars and race cars? Why do you think they are shaped the way they are?*



### Procedure:

- 1) Break up into two or three teams. Each team should have a particular color of clay.
- 2) With your team, mold the clay into different shapes and drop them into a 100 mL glass filled with soap observing how fast they reach the bottom of the glass.
- 3) Each team must choose 3 different shapes, which they believe would travel fastest in the soap. Discuss what design considerations you put into your shapes.
- 4) Relay race with your clay shapes! Use the stopwatch to see who wins.

Team #1 Shape	Team #2 Time	Team #2 Shape	Team #2 Time	Team #3 Shape	Team #3 Time

*Q7. Which shapes traveled the fastest?*

*Q8. Why do you think those shapes worked well? How does performance relate to drag?*

*Q9. What combination of fluid medium and clay shape would have produced the best performance results? How does this relate to viscosity and drag?*

*Q10. Thought Exercise: Based on what you have observed with the clay shapes, rank the following from most to least drag. (1=most, 4=least)*



## Part III – Polymers

### Key Concepts:

- A **polymer** is a large molecule chain that is made up of a repeating structural units linked by chemical bonds.
- Polymers are everywhere! What are some polymers that we use and see every day? Plastic is a polymer that we use all of the time --- in our nalgene bottles, vegetable grocery bags, and snowboards. Silly putty is also a polymer!



- How about in your body? DNA and proteins are polymers too!
- As you will observe, polymers can behave as **solids** and **liquids**. In other words, they are **viscoelastic**.
- The length of the polymer chains, the chemical structure of the repeat units, and the arrangement of the various repeat units in the polymer can affect the way the polymer behaves at different temperatures, ability to form crystal structures, and their melting points. Thus, as we will see, different polymers such as silly putty and cornstarch and water will behave differently.

## Silly Putty

### Procedure:

- 1) Roll some of the silly putty into a ball and place it on top of the opening of a CD hole. Observe after 30 minutes.
- 2) In the meanwhile, play around with your silly putty! Pull it rapidly and slowly and observe.
- 3) Roll the silly putty into a ball and try to bounce it.

*Q11. What happened when you pulled the silly putty rapidly?*

*Q12. What happened when you pull the silly putty slowly*

*Q13. Does the silly putty stretch?*

*Q14. Does it go back to its original shape when you release it after stretching?*

*Q15. Does it bounce?*

*Q16. What happened to the ball of silly putty on top of the CD hole?*

*Q17. Is silly putty a liquid or a solid? Does it have properties of both? What does this tell us about polymers?*

## Cornstarch and Water

### Procedure:

- 1) Add 1 cup of cornstarch for every  $\frac{1}{4}$  cup of water into a bowl and mix. Keep adding water until the mixture appears a little thicker than pancake batter.
- 2) Get your hands dirty! Smack the cornstarch and water mixture.
- 3) Pour it from hand to hand.
- 4) Roll it into a ball and keep rolling, then stop.

*Q18. What happened when you smacked the cornstarch and water? Did it feel like a solid block or a liquid?*

*Q19. What happened when you poured it from hand to hand? Did it flow?*

*Q20. Did the cornstarch and water take the shape of a ball?*

*Q21. How is the cornstarch and water like the silly putty? Do they exhibit properties of fluids or solids?*

*Q22. What can we learn about some of the properties of polymers from these experiments?*

### Watch these videos to learn more about fluids!

Walking on water (and cornstarch)! <http://www.youtube.com/watch?v=f2XQ97XHjVw>  
50 lb ball of silly putty <http://www.youtube.com/watch?v=uWYxc8xhihg>  
Reversible Fluid Flow [http://www.youtube.com/watch?v=p08\\_KITKP50](http://www.youtube.com/watch?v=p08_KITKP50)