

# Viscosity Lab

Objective: to determine the viscosity of Karo syrup

Theory: An object falling through a viscous medium will reach a terminal velocity (constant velocity, no acceleration) when the sum of the buoyant force and the viscous force equals the force of gravity. For a sphere of radius ( $r$ ) in a fluid of density ( $\rho$ ),

$$F_{\text{buoyancy}} + F_{\text{viscosity}} = F_{\text{gravity}}$$

$$F_b = \frac{4}{3} \pi r^3 \rho g \quad F_v = 6 \pi \eta r v_t \quad F_g = m g$$

where  $v_t$  is the terminal velocity and  $\eta$  is the viscosity.  $g$  is given as  $980.7 \text{ cm/s}^2$

Procedure:

1. Determine the density of the Karo syrup ( $\text{g/cm}^3$ ). Record this and the temperature of the syrup ( $^{\circ}\text{C}$ ).
2. Measure the diameter of the ball bearing and a marble. Record diameter of each type in cm.
3. Find mass of ball bearing and average mass of marbles. Record in grams.
4. Using the masking tape, mark off center 50. cm section of plastic tubing (between stoppers). Make certain there is 50. cm between inside portions of tape markers. **MAKE CERTAIN THE BOTTOM STOPPER IS INSERTED TIGHTLY.** Angle tubing at a  $45^{\circ}$  and add syrup to a height 2 cm above the top masking tape marker. Try to add the syrup so that no bubbles form in the column by pouring it down the side of the tube. Place tube upright in clamps.
5. Practice dropping and timing the ball bearing as it falls through the column. You must start timing when the center of the ball appears under top piece of tape and stopping when the center of the ball passes behind the bottom piece of tape. Use the magnet to lift the bearing back to the top of the syrup column. Repeat 10 times and record all fall times. This time will allow you to calculate the velocity of the marble. Velocity is defined as distance traveled (50. cm here) divided by the time taken (your average of the ten trials). Next drop the ten glass marbles and record the time for each. Calculate the average terminal velocity of the glass marble as well.
6. Using the formula:  $F_{\text{buoyancy}} + F_{\text{viscosity}} = F_{\text{gravity}}$  solve for the viscosity of the syrup first using your terminal velocity average for the ball bearing and then for the glass marbles.

Final formula registration:  $\frac{4}{3} \pi r^3 \rho g + 6 \pi \eta r v_t = m g$

7. Compare the viscosities you just found (percent difference formula).
8. Compare the average of the two viscosities with the known value for Karo syrup (using percent error formula).

Report should include all data in clean, tabular format along with all mathematical work. Show all your set-up work, with units, to receive credit. Place final viscosities along with percent difference and percent error in a table as well. Bonus credit is available for working viscosity with volcanoes problems (required in Honors).

## Viscosity Notes

Viscosity is an internal property of a fluid that offers resistance to flow. For example, pushing a spoon with a small force moves it easily through a bowl of water, but the same force moves mashed potatoes very slowly. In fact, one of the major differences between styles of mashed potatoes is the viscosity of the starchy mass: some people like their potatoes running and teeming with milk and butter (they are fans of low-viscosity potatoes), while others like their potatoes drier and stickier, so they almost crack rather than flow (these people are devoted to high-viscosity potatoes).

There are many ways to measure viscosity, including attaching a torque wrench to a paddle and twisting it in a fluid, using a spring to push a rod into a fluid, and see how fast a fluid pours through a hole. We will see how fast a sphere falls through a fluid. The faster the sphere falls, the lower the viscosity. If the fluid has a high viscosity it strongly resists flow, so the sphere falls slowly. If the fluid has a low viscosity, it offers less resistance to flow, so the ball falls faster.

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where  $v_t$  is the terminal velocity and  **$\eta$  is the viscosity**.  $g$  is given as  $9.807 \text{ m/s}^2$

Alternate formula:

$$\text{Viscosity } (\eta) = \frac{2(\Delta\rho) g a^2}{9 v}$$

where  $\Delta\rho$  = difference in density between the sphere and the liquid,  $g$  = acceleration of gravity,  $a$  = radius of sphere, and  $v$  = velocity ( $d/t$ )

Viscosity can be measured in different unit systems. The SI unit is  $\text{N s/m}^2$  which is known as the poiseuille (PI). An older unit, the poise ( $\text{dyne s/cm}^2$ ) remains in common use (where  $10 \text{ poise} = \text{N s/m}^2$  and  $100 \text{ centipoise} = 1 \text{ poise}$ ) ( $1 \text{ Pa s}$  or Pascal second is also used).

In order to understand what viscosity is, you need to realize that it is the ratio of the shear force applied and the amount of resulting deformation. The deformation of the fluid is expressed as the rate of shear. Therefore, viscosity is the relationship between shearing stress and rate of shear.

In the simplest cases, like water or aqueous solutions, the shearing stress is directly proportional to the rate of shear. The proportionality constant is called the viscosity coefficient or the viscosity of the liquid. Fluids where the proportion is direct are called Newtonian.

## Newtonian and Non-Newtonian Fluids

Fluids, including finished beverages, are either Newtonian or Non-Newtonian. The simplest are the Newtonian ones, like water, dilute suspensions, aqueous solutions, and emulsions. Viscosity is temperature dependent and typically decreases as the temperature rises. Other examples of Newtonian fluids include some motor oils, most mineral oils, gasoline, kerosene, most salt solutions in water.

Non-Newtonians are a group of liquids that change viscosity when they are stirred, shaken, or otherwise agitated.

Ketchup becomes thicker, or more viscous, when it sits still. If you stir it up or shake it, it becomes thinner, or less viscous. Ketchup is a thixotropic liquid. It becomes less viscous when agitated. It is similar to Visplex (a drilling fluid). This fluid is a liquid while in motion, but when at rest it turns into a thick gel. This makes it useful because when the circulation of the drilling fluid stops, the gel suspends the rock cuttings and prevents them from sinking to the bottom of the borehole. Other thixotropic liquids include most paints, silica gel, greases, inks, milk, mayonnaise, asphalt, glues, molasses, starch, lard, and fruit juice concentrates). Theory: Ketchup that has been standing still is thicker (more viscous) than ketchup that has been stirred or shaken. Part of this comes from the nature of the macerated tomatoes. The solid part of the fruit must form suspended microfibrils when ground up. On standing still the fibrils in such a suspension increasingly make contact with each other and stick together. This forms a 3-D structure or gel throughout the fluid, the strength of which increases with time. The gel structure is broken by agitation, reducing the viscosity. Ketchup also contains xanthan gum, a thickener. This gum dissolves in water to form a thixotropic gel. The gum polymer molecules are very much smaller. The rod-like polymer molecules also build a structure with time. There may also be some gels arising from pectin if there is any in the tomato paste. Pectin is also a soluble polymer that has the power to form a cross-linked gel with sugars.

Another non-Newtonian liquid is a mixture of cornstarch and water. It also acts differently depending on whether it is still or agitated. But the behavior is the opposite of ketchup. This kind of fluid is called dilatant. It becomes more viscous when agitated or compressed.

Theory: To start thinking about why the cornstarch and water mix behaves the way it does it may help to realize that it is not a simple liquid like water, oil, or corn syrup. It is a suspension. The tiny granules of cornstarch do not dissolve in the water. Rather they are mixed in with the water but remain intact and solid. In a salt water mixture, the salt dissolves in the water. There are no chunks of salt floating around.

The most generally accepted explanation for the behavior of the cornstarch water mix is that when sitting still the granules of starch are surrounded by water. The surface tension of the water keeps it from completely flowing out of the spaces between the granules. The cushion of water provides quite a bit of lubrication and allows the granules to move freely. But, if the movement is abrupt, the water is squeezed out from between the granules and the friction between them increases rather dramatically.

Another possible explanation: Cornstarch molecules are in long chains called polymers that get stretched when the mixture is compressed. They may also get tangled so as not to slide easily against each other. It would make sense that stretched fibers would offer more resistance to movement, just like the resistance of a taut rubber band or a coil spring under tension. But the

tangling argument doesn't explain why rapid motion increases viscosity. Wouldn't the fibers be tangled when the mixture is moving slowly or still? In fact, rapid motion might break the fibers. Another problem with this model is that the starch is not separated into molecules, but rather exists as much larger granules, which are essentially spherical. These granules will dissolve with heat. A cornstarch and water mixture pouted into a sauce during cooking will thicken it. This will only happen if the sauce is hot. We should also note that a mixture of fine sand and water exhibits behavior similar to the cornstarch and water mix, but sand molecules are not polymers. Static electricity has also been presented as a possible explanation.

The first explanation seems to be the most convincing. The starch granules are monodisperse, meaning that they are all about the same size. This is known to increase dilatancy, perhaps allowing more rapid drainage of water on pressing that would be the case with polydisperse (broad particle size distribution) particles which can pack together more closely.

Other dilatant mixtures: starch in water, beach sand, quick sand, candy compounds, peanut butter.

To summarize:

thixotropic = viscosity decreases as stress increases, but, given time, returns to original.

dilatant = viscosity decreases non-proportionally as the shearing stress and rate of shear increase

Thanks to an excellent web site produced by the SEED Foundation ([www.slb.com/seed/](http://www.slb.com/seed/)) for the above information. The web page dealing with the above information on viscosity is: [http://www.slb.com/seed/en/notes/liqu\\_gui.htm](http://www.slb.com/seed/en/notes/liqu_gui.htm) found on the SEED web site. They also have virtual a viscosity experiment at [http://www.slb.com/seed/en/lab/visco\\_exp/index.htm](http://www.slb.com/seed/en/lab/visco_exp/index.htm).

## *Viscosity with Volcanoes*

Viscosity is important in volcanology. The more fluid a magma, the more likely it is to erupt. On the other hand, when more viscous (higher viscosity) lavas do erupt, they usually do so explosively. Viscosity also affects the shapes of lava flows and the mountains they erupt from. The more viscous the magma, the fatter the lava flow. Also, the more viscous the magmas a volcano erupts, the steeper the volcano. Thus, shield volcanoes like we have in Hawaii have gentle slopes (less than 10 degrees) while stratovolcanoes like the Cascades in the northwestern mainland are much steeper (roughly 25 degrees). As expected, Hawaiian volcanoes erupt more fluid lavas (called basalt) than do the Cascade volcanoes, which erupt a lava called andesite.

Viscosity Calculations:

Jefferys (1925) derived a formula to calculate the viscosity of a fluid based on its physical properties and flow characteristics. The formula is:

$$V = \frac{g h^2 \rho \sin A}{3 \eta}$$

where  $V$  is the mean velocity of the flow,  $g$  is the coefficient of gravity ( $9.807 \text{ m/s}^2$ ),  $A$  is the angle of the slope,  $h$  is the depth of the flowing liquid,  $\rho$  is the density of the liquid (cool, basaltic rock has a density of  $2.65 \text{ g/cm}^3$  so the hot, basaltic lava must be less than this - MacDonald used a value of  $2 \text{ g/cm}^3$ ), and  $\eta$  is the coefficient of viscosity ( $\eta$  is the Greek letter eta).

MacDonald (1954) calculated the viscosity of lava during Mauna Loa eruptions he observed in 1940, 1942, 1949, and 1950. Geologists realized they could apply this equation to flowing lava to estimate its viscosity. In the field he measured the angle of the slope, depth of lava, and velocity of flow. Angle of slope can be measured from a compass or calculated from a topographic map. The depth of the lava channel is used as an approximation of the depth of the lava. Velocity is calculated by throwing a stick on the surface of a flow and measuring the amount of time it travels a premeasured distance. The acceleration of gravity and density of the liquid are constants.

Use MacDonald's estimates and the equation to calculate the viscosity. The units for viscosity used by MacDonald are poises. A poise is  $1 \text{ g/an s}$ . Therefore, to make the calculations, all measurements must be converted from meters to centimeters.

Date	Location	Speed (m/s)	Lava depth (m)	Slope angle	Viscosity (poise)
4/ 12/40	Side of cone at vent	6.7	1	20	
5/4/42	Edge of core at vent	8.3	2	6	
1/20/49	cascade 0.6 km from vent	13.3	2	15	
6/1/50	Entire Honokua flow	2.7	2	10.5	
6/2/50	Cascade in Kaapuna flow 20 km from vent	11.1	2	17.5	
6/2/50	Lava river in Kaapuna flow 20.5 km from vent	6.9	3	8	
6/7/50	cascade cose to vent	13.9	1.5	25	

Based on your calculations, answer the following questions:

1. Which eruptions had the lowest viscosities?
2. Why are the viscosities low for these eruptions?
3. Which eruptions had the highest viscosities?.
4. Why is the viscosity high for these eruptions?
5. In general, do the estimates show that viscosity increases with distance from the vent?