

Earth Forces Silly Putty Lab

1. Description

In this lab you will measure the viscosity of silly putty using two approaches: (a) “order-of-magnitude” measurements which do not involve any special instruments and (b) accurate measurements using a rotational viscometer.

2. Order-of-magnitude measurements of the viscosity of silly putty

Make a brick with a height of approximately $H \approx 1$ cm and horizontal dimensions $L \times W$ (perhaps a few centimeters in each dimension - it depends on the volume of your silly putty). Measure L and W and estimate the surface area $A = LW$. Put your hand on top of the silly putty and shear it slowly by applying pressure. Try to avoid slipping and also make sure that your palm covers the whole surface of the silly putty as uniformly as you can. Estimate the time interval t (it will probably be of the order of several seconds) during which you applied the force and the horizontal displacement x of the upper surface of the silly putty.

The strain ϵ can be estimated as

$$\text{strain} = \frac{\text{horizontal displacement}}{\text{layer thickness}} \quad \text{or} \quad \epsilon = \frac{x}{H} \quad (1)$$

The best results are obtained when the displacement x is of the order of the silly putty thickness H . At larger displacements the shape of the silly putty changes substantially.

The strain rate can be calculated as

$$\text{strain rate} = \frac{\text{strain}}{\text{time}} \quad \text{or} \quad \dot{\epsilon} = \frac{d\epsilon}{dt} = \frac{\epsilon}{t} \quad (2)$$

To estimate the force that you apply to the silly putty imagine how much weight m your force would lift. If you are unsure even about the order of magnitude of m , try to first put an upper bound on m (for example, it is highly unlikely that this would be more than 100 kg). Then try to put a lower bound (for example, it is highly unlikely that this would be less than 10 g). Choose a value in between. Note that in order-of-magnitude estimates, “in between” means in between on logarithmic scale. For example, if the upper and lower bounds are 100 kg and 10 g respectively then the number that is between $\log_{10}(0.01) = -2$ and $\log_{10}(100) = 2$ is $((-2) + 2)/2 = 0$ that is $m = 10^0 = 1$ kg. Using $g \approx 10 \text{ m s}^{-2}$, the force can now be estimated as

$$F = mg. \quad (3)$$

Estimate the shear stress and the viscosity:

$$\text{shear stress} = \frac{\text{“shear force”}}{\text{surface area}} \quad \text{or} \quad \sigma_s = \frac{F}{A} \quad (4)$$

$$\text{viscosity} = \frac{\text{shear stress}}{\text{strain rate}} \quad \text{or} \quad \eta = \frac{\sigma_s}{\dot{\epsilon}}. \quad (5)$$

3. Measurements of the viscosity of silly putty using a rotational viscometer

The idea of rotational viscometer is very simple. The viscometer rotates a sensing element, which is called a spindle, and measures the torque necessary to maintain a given rotation rate. This torque can then be converted to viscosity. We will use Brookfield Rotational Viscometer with a Helipath Drive Unit designed for very high viscosity fluids. It uses a special T-bar type spindle which not only rotates but also slowly (at about one inch per minute) moves up and down to prevent “channelling”.

Slide the T-bar spindle F (the smallest spindle) into the chuck and tighten the spindle-chuck-closer-weight assembly (first tighten the closer, then the weight). Very gently push up on the viscometer coupling screw, avoiding any side to side movements, and, holding it securely, screw the spindle assembly on. [**Note: (a) The coupling screw thread is left-handed. (b) The viscometer’s spring is very sensitive.**] Adjust the stops so that in the uppermost position the spindle is above the surface of the silly putty while in the lowermost position the bottom of the spindle is at least 1/2” from the bottom of the silly putty and the bottom of the spindle assembly is at least 1/2” above the surface of the silly putty. Position the spindle about 1/4” above the silly putty and lower the spindle into the silly putty by turning the Helipath Drive Unit on for a short time (with the direction of the Helipath Drive Unit set to down), until the T-bar is immersed into the silly putty about 1/4” below the surface.

Set the rotation speed to 0.5 revolutions per minute (*RPM*) and make sure the Helipath Drive Unit is off. Turn the viscometer on and allow for about one revolution and turn the Helipath Drive Unit on. Take multiple dial readings (% torque display) as the T-bar travels through the helical cycle. When the T-bar exits the silly putty, turn the Viscometer and the Helipath Drive Unit off. Repeat the experiment at $RPM = 1$ and 2.

To convert the torque T to viscosity η use the conversion formula:

$$\eta = \frac{T \times CF}{RPM} \text{ (Pa s)}, \quad (6)$$

where T is the torque magnitude in terms of the percent of the viscometer’s maximum value (a value from 0 to 100) and CF is the conversion factor ($CF = 800$ for spindle F). Note that the maximum viscosity that can be measured with this viscometer is $1.6 \cdot 10^5$ Pa s.

Analyse the results. First, estimate the errors in determining the viscosity. The errors in the torque measurements are 1% of the full scale: $\Delta T \approx \pm 1$. However, the total errors are much higher because of all sorts of factors: the dial is not fully stabilized, the torque depends somewhat on how deeply the spindle is immersed into the silly putty, the channelling effect and, perhaps most importantly, the viscosity of silly putty is non-Newtonian. So, you will get a more realistic estimate of the errors from the actual variations in your measurements. Compare the value obtained using the viscometer with your order-of-magnitude estimates. Compare the viscosity of silly putty with the viscosity of other fluids: water (10^{-3} Pa s), honey (10 Pa s), basaltic magmas (10^2 to 10^3 Pa s), rhyolitic magmas (10^3 to 10^5 Pa s).