Volcanoes and Earthquakes—Viscosity Lab Walkthrough

Earth Science Essentials
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See walkthrough example report below.

Materials: You need a set of measuring cups and a marble. In addition, you will need to get a tall clear glass, a bag of sugar, a timer, a ruler, a spoon or knife for stirring, and water.

Goal: Measure and graph how the viscosity of sugar water changes with composition and use your results to make predictions about experiments you didn't do.

Concept of Viscosity: A viscous material does not 'spring back' when force on it is released. It will deform under even a very low force, with the rate of deformation related to the amount of force applied. More viscous fluids will flow less quickly and a marble will fall through them more slowly. Viscosity in these experiments is proportional to the inverse of the rate of marble drop.

Outline of tasks:

1) Mix sugar and water in several different proportions and measure how long it takes a marble to drop through the liquid. You might want to consider what compositions you want to make. You need a wide enough range of compositions and enough different compositions so you can clearly see the relationship between deformation rate of the liquid and its composition. You need to be able to time how long the marble takes to fall—if it falls too quickly you can't measure precisely and if it falls too slowly you won't have time to wait for it to complete its fall. Another consideration is that sloppy mixing of compositions, or sloppy measurements, results in slop, not science.

2) Choose appropriate units. How will you report the concentration of sugar in your water? Percent by volume? Percent by mass? Fraction by volume? Total sugar divided by total water? Amount of sugar? In general, amount of sugar is a poor unit because the properties of interest, like viscosity, don't depend on the amount of sugar, they depend on the amount of sugar relative to water.

3) Take appropriate measurements. Deformation rate is a—well, it's a *rate*. That means you need to divide a distance by a time. How far does the marble fall in a given amount of time? Or, how long does it take to fall a given distance?

4) Plot an appropriate graph. You are measuring the effect of one variable (composition of sugar water) on another variable (viscosity of the fluid)--independent variable and dependent variable. You need to use an x-y type graph to show the relationship between these two variables—not a pie chart, or a bar graph, or some other kind of figure. By convention, we often plot the independent variable on the x axis and the dependent variable on the y axis.

5) Interpret your results. Does viscosity (as measured by marble-drop-rate) change with composition? Is that change significant given the uncertainty in your measurements? What is your uncertainty and how to you determine it (hint: repetition). In what way does the viscosity change? Does it increase or decrease with increasing sugar concentration? Does the viscosity change linearly with composition or is that change non-linear?

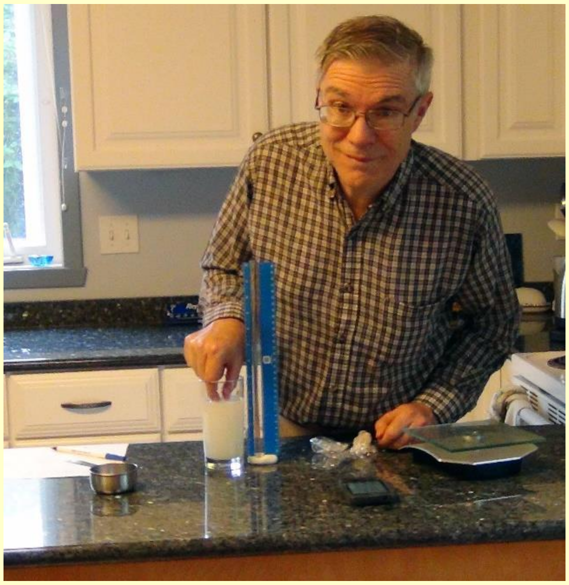
6) Based on your experimental results, predict the composition of sugar water is required for the marble to take 24 hours to fall through 5 inches of sugar water. Show all your work with well-organized math calculations and clear, well-labeled explanations.

Report:

Your report should include pictures of you doing your experiment, your experimental set up and procedures, any problems you encountered and how you solved them, and of course all of the items requested above.

Viscosity Lab Walkthrough—

Experimental Procedures. I dropped a glass marble from the surface of sugar water solutions of different composition contained in a clear water glass (see picture) and timed how long it took for the marble to fall to the bottom of the glass.



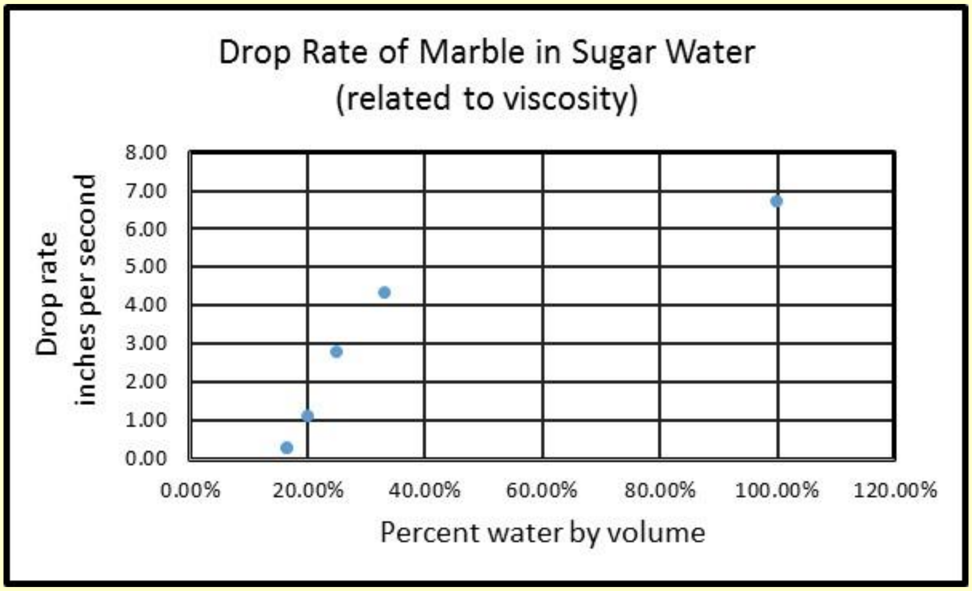
Due to the difficulty in timing the marble fall-time while I was also dropping it and watching when it hit the bottom, I got someone else to run the timer while I dropped the marble and observed when it hit bottom.

Experimental Results. Compositions of sugar water, distance that the marble fell, and the time it took to fall are given in the table below, along with the calculated fall rate (velocity).

Comp	1rst tiral	2nd trial	3rd trial	average	height	Drop rate
33.30%	0.69	0.83	0.83	0.78	3.38	4.31
25.00%	1.53	1.53	1.46	1.51	4.19	2.78
20.00%	3.07	3.00	3.35	3.14	3.50	1.11
16.70%	10.89	12.26	11.31	11.49	3.19	0.28
16.70%	13.27			13.27	3.94	0.30
100.00%	0.62	0.62	0.55	0.60	4.00	6.70

Composition is in volume percent water. Trial values are marble drop times in seconds. Height is the distance that the marble travels through the liquid in inches. Drop rate is in inches per second.

Results are shown graphically below. To demonstrate that changing the distance that the marble falls through the water does not produce a difference in drop rate, I repeated the experiment in the 16.7% water solution but with a different drop distance in the liquid. As seen in the figure, the results are not meaningfully different.



Uncertainties in the 100% water composition are relatively higher than in other compositions because the reaction time to turn my phone stop watch on and off were a significant fraction of the total time for the marble to fall. The third trial time for the 20% water composition may be high because I had let my fingers get sticky with sugar and the marble stuck to my fingers for a moment when I released it.

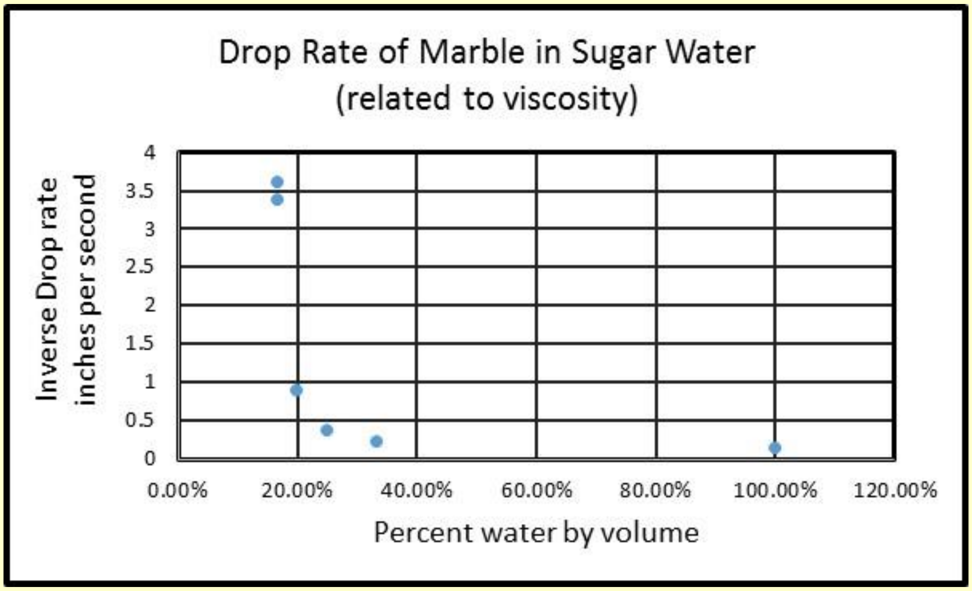
Interpretations: The drop rate decreases significantly as the percent water decreases and percent sugar increases. Since viscosity in inversely proportional to drop rate, this means that viscosity increases significantly as sugar concentration increases. Halving the percent water increases the drop time by a factor of nearly 15. The variation in drop rate with composition is not linear—the drop increases more sharply as the amount of sugar increases.

Based on the relatively small variations seen between repeated experiments (reported in the table above), the change in viscosity with composition is much larger than any uncertainties in the measurements themselves.

The drop rate required for a marble to sink 5 inches in 24 hours is 5"/(24hrs*60min/hr*60sec/min) = 0.000058 inches per second. Projecting to this drop rate in the figure above would give a concentration only slightly more sugar-rich than the most sugar-rich experiment—perhaps about 16% water.

However, reason suggests that the trend seen in the figure above cannot continue linearly toward higher sugar concentrations because this would result in negative drop rates, for example at 10% water. A negative drop rate does not make physical sense—the marble isn't going to 'unsink' or fly up into the air.

What's happing at very high sugar concentrations becomes more obvious if we convert our sink rate into inverse sink rate (proportional to viscosity) as shown in the figure below.



In this case, our drop rate for a marble sinking in 24 hours converts to an inverse drop rate of 17280 seconds per inch. This occurs far above the conditions plotted on the graph and far outside the conditions of our experimental measurements. I conclude that the exact concentration where this inverse drop rate of 17280 would occur is not clear from my measurements.

Changing the composition of the sugar water changes the density of the liquid in addition to its viscosity. This changes the buoyancy of the marble and thus the net force acting on it. I did not take this buoyancy force into account in thinking about viscosity in this report.

<u>Other experimental notes</u>: It's important to provide enough information in a scientific report so that a later researcher can reproduce your results. The following information would be needed by anyone trying to reproduce my results.

I was too impatient to wait for the sugar to completely dissolve in the water. To maintain reproducibility, I stirred the sugar into the water frequently to keep it from settling to the bottom and affecting my results.

Density and size of the marble might make a difference if someone tried to reproduce my results. My study used a glass marble that was 1.3cm in diameter yielding a volume of 1.15 cm^3. I measured its mass on a kitchen scale as 3 grams, giving a density of 2.6 g/cm^3—but the kitchen scale I used only measured to the nearest gram, so the actual density could be as low as $2.5/1.15cm^3 = 2.2\ g/cm^3$ or as high as $3.5/1.15cm^3 = 3.0\ g/cm^3$. Typically this kind of glass is close to 2.6 g/cm^3.

In this study I report concentration as percent water by volume—however, the granulation of sugar can influence how much sugar is in a cup. So that other researcher can reproduce my results, I measured the mass of a cup of sugar as used in my experiments as 222 grams per cup. This compares to a mass of 1 cup of water at about 237 grams, so reporting volume percent sugar is not greatly different from mass percent.

Dropping the marble from any height above the liquid will make a difference in the result because part of the time the marble will be falling through air, not through sugar water, and when it hits the sugar water it will have a non-zero velocity. The higher you go above the liquid, the more the experiment becomes an impact experiment and not a viscosity experiment. In my experiments, the marble started at the surface of the liquid.