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CTE Science Laboratory Investigation

EXPERIMENTAL DETERMINATION OF VISCOSITY

**Background Information**

Viscosity can be generally defined as the resistance of a fluid to flow. More specifically, it is the resistance of a fluid to being deformed by a sheer or tensile stress. A sheer stress is a force that is applied parallel to an object, while a tensile stress is a force that pulls on an object. Both of these stresses might be experienced by a fluid in a tube. For example, the fluid that is in contact with the sides of the tube would experience a sheer stress in the opposite direction of flow. In a liquid with a high viscosity, the fluid would resist this flow. If the fluid had a low viscosity, then the fluid would flow easily.

The most common place for people to encounter viscosity is with engine oil. The viscosity of engine oil is measured by the Society of Automotive Engineers, and is not expressed in a standard unit, but rather with a rating that the Society developed. Most modern oils are blends of different kinds of compounds, and are expressed as “5W-20” or “10W-30.” The first number (the one before the “W”) refers to the flow of the oil when at zero degrees Celsius, while the last number refers to the oil when it is at 100 degrees Celsius.

Viscosity is measured, by civilized people, at any rate, in a rather funky metric unit called the pascal-second, abbreviated Pa·s. A pascal is the unit of pressure in the metric system, and it is equal to a force of one netwon spread over an area of one square meter (that’s not a lot of force; a small apple in your hand exerts about one newton of force). Combine it with the second, and you get how long it takes for a given pressure to push a fluid past a point.

The formula that we’ll use to determine viscosity looks complicated, but when you take it apart, it makes an awful lot of sense. Viscosity can be expressed as:

2(Δρ)ga2

η =

9v

Where η (the greek letter eta) is the viscosity of the fluid being tested, Δρ is the difference between the density of the falling sphere and the liquid being tested (delta is a greek letter that means “change in,” and rho is the greek letter used for density), g is the acceleration due to gravity, a is the radius of the sphere and v is the velocity of the falling sphere.

The acceleration due to gravity should be constant (assuming you are performing your experiment fairly close to the earth…), and should always equal 9.81 m/s/s, or to put the unit another way, m/s2. Just the same, the radius of your sphere should remain constant (although you must measure it), unless you shave a bit off it.

The difference between the density of the sphere and that of the liquid being measured can easily be determined. Simply find the mass and volume of each, using the appropriate laboratory equipment, then take the difference. The velocity must be measured as well, and we will do that today using photogates. As a less-exact alternative, you could time how long it takes the sphere to fall the given distance, but as it will be relatively small, the accuracy of your timing will be reduced.

Knowing all this will get us the result, but remember, we must express it in Pa·s. The formula contains many elements with different values. We can perform a dimensional analysis of the formula to see what the fate of the units will become. Below, find the formula without the actual elements, but rather with only the units that those elements use (note that because your kind and caring teacher detests dividing by a fraction, the denominator (that is, the “9v” from the original formula) has been moved to the numerator and inverted, represented by the “s/m” in the formula below):

Kg

m3

s

m

m2

1

m

s2

η =

If we cancel out all that we can, we are left with:

Kg

m·s

η =

Which is equivalent to the unit of viscosity that we discussed before, the Pascal-second.

Knowing all that, we can now fairly accurately determine the viscosity of several common liquids using our viscometer. As an interesting note, there is one famous experiment that sought to prove that pitch (a thick, tar-like petroleum fraction) is indeed a liquid, albeit one with a very high viscosity. The experiment began in 1930 in Queensland, Australia when Thomas Parnell, a professor at the local university, put some pitch in a funnel and waited. The first drop fell in December of 1938, and the eighth and most recent drop fell in 2000. This provided enough data for scientists to determine that pitch is about 230 billion times more viscous than water. The viscosity of water at room temperature is .00089 Pa·s.

**Purpose**

The purpose of this investigation is to experimentally determine the viscosity of several common liquids, and to understand how the formula provided can aid us in doing so. We will also investigate the concept of dimensional analysis in showing that one value, even if expressed in a different unit, can be the same as another value.

**Materials**

Viscometer Calculator

Sphere Several common liquids

PENCIL Photogates

Lab Pro or computer Ring stands

**Procedure**

1. Clamp the viscometer to the ring stand.

2. Using other ring stands, position one photogate at the top of the viscometer and one at the bottom. Measure the distance between them as accurately as possible. You should measure from the middle of one photogate (where the infrared sensor is) to the middle of the next one.

3. Note the measurement in your data table, and enter it into the Lab Pro or computer as demonstrated by your kind and caring teacher.

4. Find the density of the sphere using water displacement and a balance. Record the data in your data table.

5. Find the density of the liquid to be tested by measuring both its mass and volume. Recall that one cubic centimeter is equal to one milliliter. Record this information on your data table.

6. Fill the viscometer with the liquid to be tested.

7. Drop the sphere into the liquid, making sure that it passes through both photogates. Record the time that it takes to fall in your data table

8. Use that time to calculate the velocity of the fall.

9. Repeat for two more trials, for a total of three.

10. Empty your viscometer and return all other materials whence they came.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Distance Between Photogates | Density of Liquid to be Tested | Density of Sphere | Time of Fall | Velocity of Fall |
| Trial 1 |  |  |  |  |  |
| Trial 2 |  |  |  |  |  |
| Trial 3 |  |  |  |  |  |

Table 1. Data collected during experiment.

QUESTION 1: Calculate the difference between the density of the sphere and the density of the liquid for each of your three trials. Show your work in the space below, and don’t leave any naked numbers!

QUESTION 2: If you have not already directly obtained the velocity of the fall from the computer or Lab Pro, calculate it here. Use the distance that the sphere fell and the time that it took to fall. No naked numbers!

QUESTION 3: Re-write the equation for viscosity and substitute in the values that you’ve discovered. Don’t forget to square what you need to square and follow the order of operations! Solve the equation for each of your trials. No naked numbers!

QUESTION 4: Average all your trials together to obtain an average viscosity for the fluid.

QUESTION 5: Use the interwebs to find the accepted value (make sure you have the value in metric units; there are many other, improper ways to measure viscosity) for the viscosity of the fluid that you used, and find the percent deviation for your value.

**Analysis**

QUESTION 6: Why did we have to include “g” (the acceleration due to gravity) in the formula that we used?

QUESTION 7: If you used three spheres for your trial, each having the same radius but different masses, would you have still obtained the same viscosities for each trial? Why or why not?

QUESTION 8: The viscosity of blood is around 0.003 to 0.004 Pa·s. The viscosity of water is about 0.00074 Pa·s at human body temperature. We know that blood is primarily composed of water, so what accounts for the difference in viscosities?

QUESTION 9: There is a medical condition called hyperviscosity syndrome. It presents as a series of symptoms including loss of vision or visual problems, bleeding from mucous membranes, headaches or problems with balance. Why do you think that these symptoms are observed?

QUESTION 10: We know that the Kg·m/s is equivalent to the unit for viscosity, the Pa·s. Demonstrate this with a dimensional analysis of the two formulae. (hint: one newton is equal to one kg·m/s2)