On the Relationship Between Viscosity and Surface Tension

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Summary

Flow rates and pulling forces were measured in several solutions to determine the correlation between surface tension and viscosity. Because these fluid properties arise from intermolecular bonding, a positive correlation was expected. To study the relationship between viscosity and surface tension, solutions with different concentrations of agar and flour were used. Differences in viscosity were determined by differences in flow rate. The flow rates were determined from the time that the solutions took to flow through a tube. The surface tension (Newtons/meter) was determined by the pulling force exerted on a needle placed on the surface of the solution, which was weighed using grains of rice put on a scale. Surprisingly, we found that the solutions with a higher viscosity than water had either less or the same surface tension as water, and we suspect this is due to the unchanged intermolecular bonding of water molecules (hydrogen bonding) causing surface tension as viscosity increased. A possible explanation is that the viscosity of a fluid is influenced more by the friction caused by the interactions between large molecules with a lot of polar atoms, causing attraction between them.

Introduction

Technological advances often find their inspiration in nature. Therefore, fundamental properties of the world around us are worthy of investigation. Surface tension and viscosity are two interesting properties of fluids which are related to the cohesion of the molecules in the fluid. Viscosity is the resistance of a substance to flow (1) and surface tension is a property of liquids such that their surfaces behave like a thin, elastic film (1). Surface tension is created by the inward pulling force exerted on the surface of a fluid (2). Surface tension is measured by the resistance of an object to being released from the surface of water; when the water is made more "sticky" by increasing its viscosity, it seems intuitive that the surface tension will increase. Hence the relationship between the two phenomena was investigated.

The purpose of this experiment was to study the relationship between viscosity and surface tension. The hypothesis was that if the viscosity of a fluid increased, then the surface tension would increase because the molecules were more tightly bonded. The viscosity was controlled by the concentration of flour or agar in 100 mL water. A tool was made to calculate the surface tension of the solutions. We disproved our hypothesis. It was concluded that viscosity is influenced by intermolecular attractions of agar and flour molecules, which influences the resistance when a fluid is moving, but this did not change surface tension because that is only determined by the intermolecular attraction of water molecules.

Results

The surface tension test was designed based on the fact that an inward pulling force would be exerted on the surface of the fluid and that there was internal pressure on the surface of the fluid, as described in the introduction. The pulling force would pull the needle down when it was half submerged into the water and the inward force was the same force as the surface tension.

In order to prove the surface tension measurement's validity, an experiment was conducted with dish detergent and water. Dish detergent weakens hydrogen bonding, which is the intermolecular attraction between positively charged hydrogen and negatively charged oxygen that causes surface tension (3). Thus, the solution with detergent should have possessed less surface tension. The surface tension test showed that water had an average surface tension of 0.55 N/m. The water with dish detergent had an average surface tension of 0.38 N/m. Since this result showed that the solution with detergent had less surface tension, the surface tension instrument was validated.

The viscosity test was designed based on the fact that viscosity is the resistance of a substance to flow. When a fluid's time to flow through a tube is measured, it can be converted into flow rate (the higher the flow rate, the lower the resistance). A fluid with a higher viscosity would have lower flow rate.

Viscosity tests were conducted to show the difference in viscosity between solutions. The viscosity test for agar solutions (agar concentrations: 0.0016 g/mL and 0.0021 g/mL) showed that a higher concentration of agar resulted in more time taken for the fluid to flow through the tube, with water taking the least time (Figure 1A). Less time meant that the fluid had higher speed when flowing and consequently it was concluded that the fluid had less resistance. Since viscosity is the resistance of a substance to flow, fluids that took more time had higher viscosity. Therefore, fluids with a higher concentration of agar had higher viscosity. The case was the same for flour. Solutions with higher flour concentration took more time to flow through the tube and thus had a higher viscosity (Figure 1B). The solution with a flour concentration of 0.5 g/mL stopped flowing 41 cm from the top. The resistance was too high. This solution had the highest viscosity.

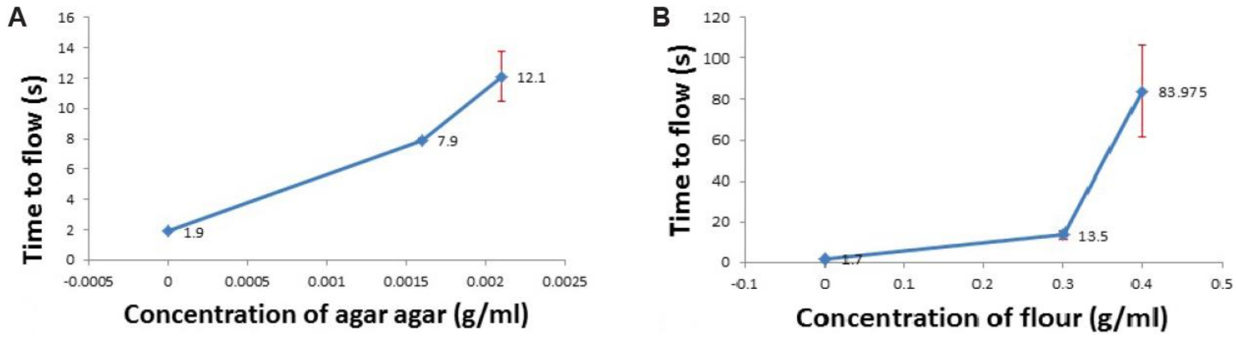


Figure 1: Viscosity measurements. A: Time(s) taken to flow through the tube (representing viscosity) over the concentrations of agar (g/mL). The higher the concentration, the higher the viscosity of agar. (Fluid Temperature: 21- 23 °C; each dot represents the average of at least three measurements.) B: Time(s) taken to flow through the tube (representing viscosity) over the concentrations of flour (g/mL). The higher the concentration, the higher the viscosity of flour. (Fluid temperature: 19.5- 20 °C; each dot represents the average of at least three measurements.)

The temperatures of the solutions were controlled around 22 °C because if the fluid gets warmer its increased kinetic energy causes molecules to each take more space, thereby decreasing attraction between molecules (4).

As shown in the results of the surface tension experiment of agar, agar solutions with higher viscosity than water had about the same surface tension as water (Figure 2A). The student's t-test indicated that the surface tension of water was not statistically different from that of the agar solutions (p-values of the student's t-test are above 0.05, Table 1).

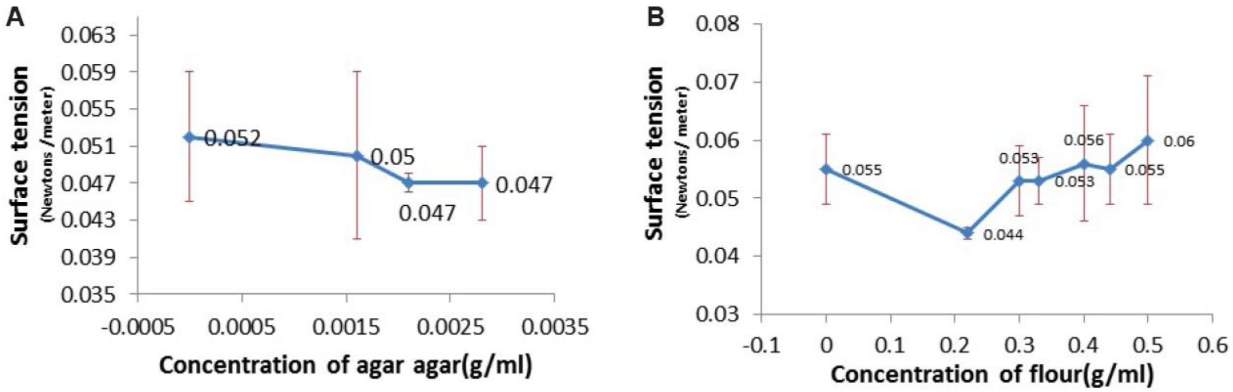
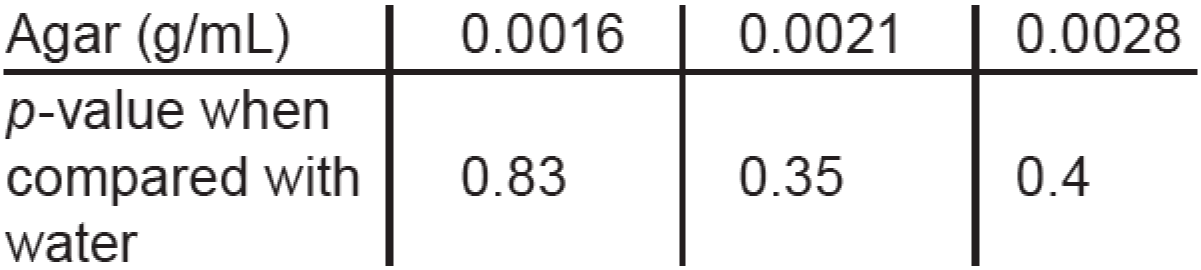


Figure 2: Surface tension measurements. A: Surface tension (N/m) over concentration of agar (g/mL) (representing viscosity). (Fluid Temperature: 21- 23 °C; each dot represents the average of at least three measurements.) B: Surface tension (N/m) over concentration of flour (g/mL) (representing viscosity). (Fluid temperature: 19.5- 20 °C; each dot represents the average of at least three measurements.)



Agar (g/mL)	0.0016	0.0021	0.0028
p-value when compared with water	0.83	0.35	0.4

Table 1: p-value of surface tension comparison of agar and water solutions (Figure 2A) by student's t-test.

Results from the surface tension experiments with flour indicated that flour solutions with a higher viscosity than water had lower or about the same surface tension as water (Figure 2B). Analysis of the results by student's t-test suggested that water had higher surface tension than the flour concentration of 0.22 g/mL (p-value is less than 0.05) and that it was not statistically different from the other concentrations (p-value of the student's t-test was higher than 0.05, Table 2).

The graph of surface tension over flow rate (cm/s) (Figure 3) and the student's t-test (Tables 1 and 2) showed that there was no statistically significant difference in surface tension between the solutions with different viscosities even when the flow rates had a difference of 75 cm/s.

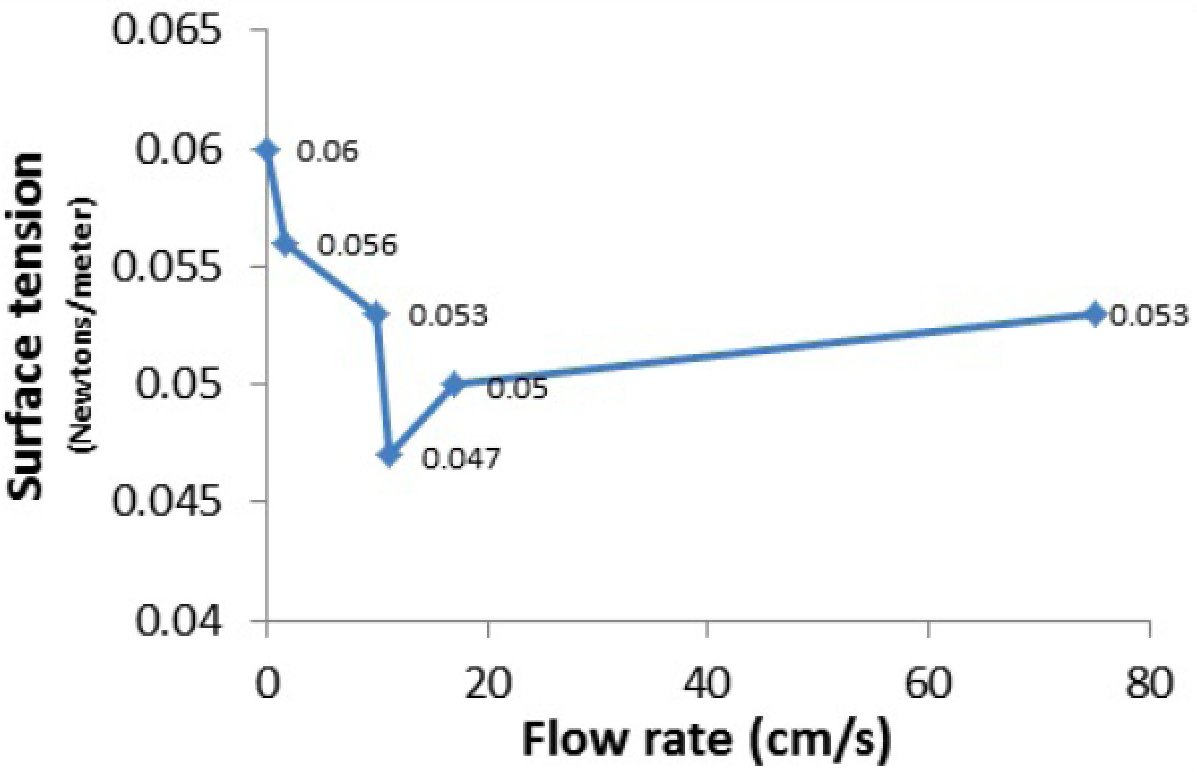


Figure 3: Flow rate vs surface tension. Flow rate (cm/s) (representing viscosity) over surface tension (N/m). (19.5 -23 °C.) Concentrations of different fluids (g/mL) from left to right: 0.5 (flour), 0.4 (flour), 0.3 (flour), 0.0021 (agar), 0.0016 (agar).

Flour (g/mL)	0.22	0.3	0.33	0.4	0.44	0.5
p-value when compared with water	0.03	0.79	0.95	0.48	0.59	0.35

Table 2: p-values of surface tension comparison of flour and water solutions (Figure 2B) by student's t-test

During the surface tension experiment with flour, a "pulling" force exerted by the surface tension could be seen when the needle was about to be released by the solution (Figure 4). Such force could also be seen when conducting the surface tension experiment with other solutions.

Figure 4: Surface tension. Just before the flour solution released the needle, the surface tension appeared to be “pulling” it.

Discussion

The hypothesis was that if the viscosity of a fluid increased, then the surface tension would increase because the molecules are more tightly bonded. It was based on the idea that when the cohesion of the molecules in a fluid is higher, the viscosity of the substance will increase and will lead to the increase of surface tension because the water molecules on the surface show more cohesion. Contrary to these predictions, the results from the flour surface tension experiment showed that water, which had the least viscosity, had higher or about the same surface tension as most of the other solutions with a higher viscosity (Figure 2B). Results from the agar surface tension experiment showed that water, which had the lowest viscosity, had about the same surface tension as all of the other higher viscosity solutions (Figure 2A). These results reject the hypothesis, since surface tension did not increase as the viscosity increased.

Viscosity can be understood as the effect of different layers of the fluid exerting shearing force on each other, or on other surfaces, as they move against each other (1). In other words, the friction between neighboring particles in a fluid causes the viscosity. Viscosity results from the strength of the attraction between the particles of the liquid (5). Surface tension can be understood as a downward net attraction exerted on the surface of a fluid (1). Hydrogen bonding causes molecules away from the surface to engage in a tug of war with their neighbors on every side and thus undergo no net attraction. However, since molecules are not present above the surface of the fluid, the molecules located on the surface are pulled inward (2). This creates some internal pressure and forces liquid surfaces to contract to the minimal area (6).

Intermolecular forces play a role in viscosity, because stronger attractions between molecules cause them to resist flow more strongly. Molecule size is also an important factor in viscosity because the attraction of intermolecular forces is stronger, so that they cause more friction. Surface tension is also a result of intermolecular forces (7). If both are related to intermolecular forces, why are they not related to each other?

Flour contains a high proportion of starches, which contain a large number of glucose molecules. The chemical formula for glucose is $C_6H_{12}O_6$ which is larger in size than water molecules (H_2O) since it has more chemical components. Therefore, starch, which is the major molecule in flour, is larger than a water molecule. Agar is a gelatinous substance. Gelatin is a mixture of peptides and proteins. Peptides and proteins are made of amino acids which have the chemical formula $RCH(NH_2)COOH$ (8). R represents the rest of the amino acid structure which is different for each amino acid (8). Amino acids are larger than water molecules because they contain more chemical components. Therefore, peptides and proteins are larger than water molecules, and thus gelatin, and agar molecules are larger than water molecules. The large molecules in flour and agar solutions have a lot of polar functional groups, which means that they have a lot of atoms which are slightly charged and attracted to each other. The results show that solutions with higher concentrations of agar and flour, which had higher viscosities than water, had practically the same surface tensions as water. Therefore, the intermolecular bonding of water, which causes surface tension via hydrogen bonding interaction was not increased when viscosity increased.

The viscosity increases when the concentration of large, charged molecules increases, which causes increased intermolecular attractions that result in resistance to flow. The hypothesis was proven wrong because the cohesion measured in the viscosity test was not the same cohesion that caused surface tension. Essentially, the viscosity test measured the resistance to flow caused by interactions between flour or agar molecules, while the cohesion responsible for surface tension was dictated by the intermolecular attraction of water. Surface tension was only caused by the intermolecular attraction of water molecules (hydrogen bonding) because adding other compounds to water did not change the surface tension (Figure 2).

The solution with the lowest concentration of flour (0.22 g/mL) had lower surface tension than water and other flour concentrations. It could be speculated that a small concentration of flour might affect the fluid's surface tension. Another explanation could be that an experimental error occurred during the mixing process or the surface tension measurement. An improvement to my experiment could be to increase the number of experiments to verify the conclusion.

This experiment explained one of the fundamental features of water, the most important and common substance on our planet. Whenever surface tension is taken into account, only the hydrogen bonds of the water molecules should be considered. Another significance of the experiment is that it shows that what might be taken for granted is not always fact. This study contributes to our fundamental understanding of water, which is important to life and research. Any knowledge gained about its function is vital for our understanding of life and the forward march of fundamental and applied research.

A future study could be conducted to determine whether temperature affects the relationship between surface tension and viscosity. A possible hypothesis is that a lower temperature would affect the interactions between the large molecules and water because the molecules have less kinetic energy.

Results show that surface tension did not increase when viscosity increased. The hypothesis was that if the viscosity of a fluid increased, then the surface tension would increase because the molecules were more tightly bonded. It was proven wrong. The idea behind the hypothesis was that the increase in viscosity, due to increased cohesion of the molecules in the fluid, would also increase the surface tension. The surface tension did not increase because surface tension is affected by the intermolecular attraction of water molecules (hydrogen bonding); however, the viscosity of a fluid is influenced more by the friction caused by the interactions between large charged molecules. The intermolecular hydrogen bonding of water molecules was apparently not changed when viscosity increased in this experiment.

Methods

Construction of equipment for the viscosity test

A transparent plastic tube 150 cm in length was taped on an inclined plane. A glass container was placed at the bottom of the tube. The tube was marked 135 cm from the top with a marker. Three milliliters of the different solutions were sucked up by a pasteur pipette and squirted out inside the top of the tube. A stopwatch was used to measure the time it took to reach the mark. This process was repeated three times for each solution. Graphs were made of time versus concentration. Time taken to flow through the tube was then converted into flow rate by dividing 135 cm (distance) by the time (s).

Surface tension test

A thin metal stick was made to penetrate through a straw (19.5 cm long) and through two plastic cups at either end of the stick at the height of 7 cm from the surface. A plastic container (3 cm high) was cleaned and tied to one side of the straw with string. A 0.051 m needle was tied to the other side of the straw with string. The weight of the two sides of the straw was balanced by adding a rubber band to the side with the needle. The position of the rubber band was adjusted to make the balance accurate (Figure 5A). The temperature of the first solution was taken. The scale was balanced and the first solution was placed under the needle. The needle was placed on the solution’s surface (half submerged, Figure 5B). Grains of rice were carefully dropped into the plastic container on the other side (Figure 5A). The process was stopped when the needle was released. The grains were counted and put into a paper holder. The date, type of fluid, and number of grains were labeled on the paper holder. The needle was cleaned and the scale was balanced. The steps were repeated at least three times for each solution. The weights of the grains were then measured on a scale, which allowed a sensitivity of 0.00001 gram. The unit of surface tension was taken as Newtons per meter (N/m) (9). The weights of the grains in grams were converted into surface tension (N/m) by multiplying the weight by 9.8*0.001 and dividing it by 2*0.051. The length of the needle was 0.051 m. Multiplying the weight by 9.8*0.001 converted it into force in Newtons. The number 0.051 was multiplied by 2 because the needle had two sides and surface tension affected both sides (10). Graphs were made of surface tension versus concentration.

Figure 5: Surface tension measurement. A: The surface tension measurement equipment was balanced before putting the needle into the water. Grains of rice were added into the plastic container after placing the needle on the surface of the water, to measure the pulling force exerted on the needle. B: The needle was half submerged in the flour solution during the surface tension test.

Making solutions

Flour solutions with concentrations of 0.20, 0.22, 0.30, 0.33, 0.40 and 0.44 g/mL were made. Dish detergent solution was made by mixing one hundred milliliters of water and 1 tablespoon of dish detergent in a cup. To make agar solutions, Gold Cup ® agar solutions with concentrations of 0.0016, 0.0021 and 0.0028 g/mL were made. Numerous experiments were done to obtain appropriate concentrations that did not solidify after a certain amount of time.

Data Analysis

Major controlled variables included temperature and wind speed. We hypothesized a relationship between viscosity and surface tension and decided to test this by making flow rate (representing viscosity) the independent variable and surface tension the dependent variable.

Data analysis: An unpaired (the solutions were different) student's t-test was done to analyze the flour and agar solutions with Excel ® to see whether there was a difference between them. When the p-value of the student's t-test is below 0.05, it can be concluded that there is a statistically significant difference between the two sets of data. The standard deviation of the results from the surface tension test was calculated with Excel ® in order to determine the variability of the results.

In order to prove that the surface tension measurement worked, a surface tension test was done using water with and without dish detergent.

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