Viscosity of Salad Dressing Lab – Instructor's Version

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Date of Experiment:

OBJECTIVES

- Students will learn about viscosity and viscosity enhancements chemicals
- Students will learn how to use a viscometer
- Students will learn to create and analyze an empirical model

INTRODUCTION

Food texture, mouth feel, and aesthetics are important properties for products in the food industry. The texture of a food and how it feels in the mouth is one of the most important selling factors, along with flavor[1]. Usually, the texture of a food can indicate the freshness or quality of the food to the consumer, so enhancing the food texture can determine whether or not the product will be purchased. The target texture of the food could be crispy, crunchy, thick, thin, fluffy, etc.

Figure 1. Salad dressing often has additives in it that make it thicker.

Consumers associate certain textures with quality of the food. Some consumer expectations are that fresh carrots should have a loud crunch, chewing gum should be soft and cohesive, potato chips should be crispy, and bagels should be soft and a little chewy. If the texture of the food does not meet these expectations, the consumer might think it is spoiled or stale. It is this reason that food companies put additives and preservatives in the food to provide a positive experience to the consumer.

Preservatives such as sodium benzoate, BHT, or ascorbic acid are added to help slow down bacteria growth and color decay. Dyes such as Blue #1, Red #40, Yellow # 5 are added to make the food aesthetically appealing, or to offset natural color loss. Flavor enhancers such as monosodium glutamate (MSG), hydrolyzed soy protein, or autolyzed yeast extract are added to enhance a food existing flavor without altering it. Fat substitutes such as olestra, carrageenan, or xanthan gum are added to provide a creamy texture without adding additional fat. Anti-caking agents such as calcium silicate, iron ammonium citrate, or silicon dioxide are added to prevent moisture adsorption in powders[2]. All of these FDA approved food additives are added to enhance the texture of the food to appeal to the consumer.

This experiment will focus on thickening agents used to enhance food texture. The effect that xanthan gum has on salad dressing will be studied. Xanthan gum is a polysaccharide produced through biosynthesis by *Xanthomonas* bacteria[3]. The bacteria is allowed to grow and ferment and produce the xanthan gum compound with the chemical structure below.

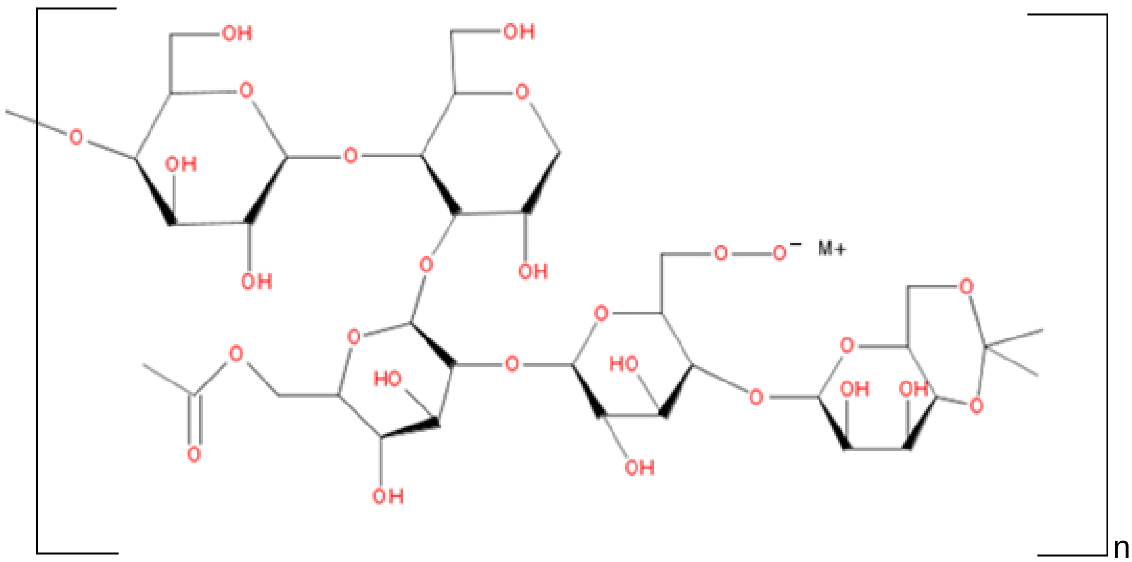


Figure 2. Structure of xanthan gum produced from *X. campestris*

The xanthan gum and solvent mixture undergoes many distillations, filtrations, and dryings to isolate the xanthan gum powder which may be later used in a variety of products.[3]

Table 1. Common applications of xanthan gum. Table adapted from García-Ochoa, F. et al[3]

Use	Concentration (%w/w)	Function
Salad dressing	0.1-0.5	emulsion stabilizer, suspending agent, dispersant
Syrups, sauces	0.05-0.2	thickener, heat stability, uniform viscosity
Baked goods	0.1-0.4	stabilizer
Pharmaceuticals	0.1-1	emulsion stabilizer in creams and suspensions
Agricultural	0.03-0.4	improve spay and increased cling in pesticides
Textile printing and dyeing	0.2-0.5	control flow of paste and prevent dye migration
Petroleum production	0.1-0.4	Lubricant in drilling

The most notable effect of xanthan gum is that increases the viscosity of the mixture it is added to. Viscosity is defined as the resistance to flow due to internal friction of the molecules[4]. This can be explained by large molecules such as xanthan gum bumping into or getting tangled with each other which gives extra resistance to free-flowing movement. In a solution, as the xanthan gum concentration increases, the probability that the xanthan gum molecules will interact and inhibit motion will increase which is measured as an increase in viscosity[4].

The viscometer measures the viscosity of the fluid by measuring the amount of torque needed to rotate the spindle immersed in the given fluid at a set speed. The spindle is driven by the motor through a calibrated spiral spring; the deflection of the spring indicates how much torque is needed and is indicated on the digital display[4].

Newton defined viscosity using the equation:

$$F' = \eta * \frac{dv}{dx}$$

Where F' is the shear stress (force per area) on the spindle, η is viscosity, and dv/dx is the fluid velocity gradient normal to the spindle. Fluids that follow this equation are called Newtonian fluids and give a linear relationship between shear rate and shear stress in addition to constant viscosity at varying shear rates as seen below[4]. Shear rate is the rate at which shear stress is being applied.

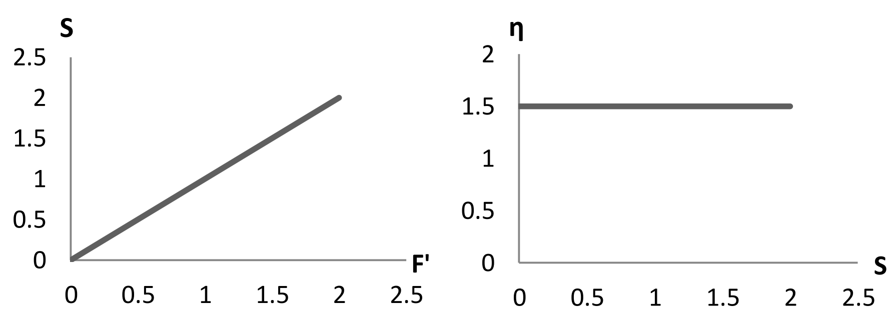


Figure 3. Newtonian Fluids: Shear rate (S) versus shear stress (F') (left) and viscosity (η) versus Shear rate (S) (right)

Non-Newtonian fluids do not have a linear relationship between shear rate and shear stress and the viscosity changes as the shear rate changes.

In this lab, you will be comparing the viscosity of commercial French dressing to homemade dressing. You will be adding xanthan gum powder to the homemade dressing to determine how much xanthan gum is in the original commercial dressing. All viscosity measurements will be done using the Brookfield viscometer.

INSTRUCTOR’S NOTE

Apparatus. This experiment was designed for operation of a Brookfield Programmable DV-II+ Viscometer. The online manual may be found here:

http://www.engr.sjsu.edu/bjfurman/courses/ME120/me120pdf/BrookfieldDVIImanual.pdf

A constant size spindle and RPM of the viscometer is needed to accurately compare the viscosity between samples. Because salad dressing is a non-Newtonian fluid, using different spindle sizes and RPM setting will result in different viscosity readings that will not accurately compare different samples. The spindle size and RPM was experimentally determined.

Salad Dressing. In this experiment ShopRite® French dressing is used, but any salad dressing or similar food product containing xanthan gum may be utilized. Be sure to note the ingredients and make sure the students have no food allergies to the materials being used. Many salad dressings contain eggs and may require refrigeration.

The following figures may be used as a reference for the instructor:

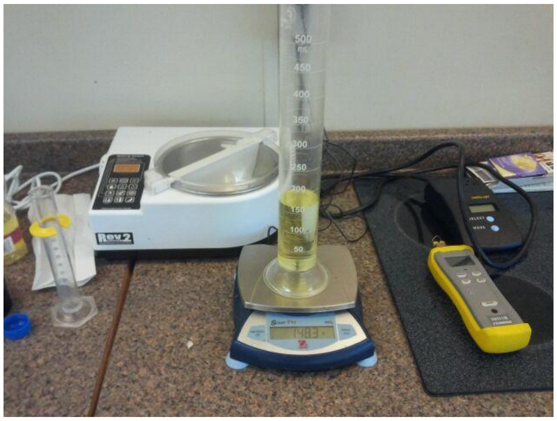


Figure 4. Measuring the mass while weighing out ingredients.

Figure 5. Separation of ingredients: Oil (top), Vinegar and water (middle), corn syrup (bottom).

Figure 6. All of the ingredients (oil, vinegar, water, corn syrup, and tomato paste) before blending.

Figure 7. Dressing after blending with no xanthan gum.
Mixture is a red-orange color.

Figure 8. Dressing after xanthan gum is added.
Mixture is a bright yellow-orange color.

MATERIALS NEEDED

- 300-400 mL beaker
- Brookfield Programmable DV-II+ Viscometer
- French Dressing*
- Purified Water
- Vegetable Oil*
- Cider Vinegar*
- Corn Syrup*
- Tomato Paste*
- Food Processor/Blender
- 200mL Graduated Cylinder

Material	**Vendor**	**Grade**
Xanthan Gum	Essential Depot	USP FCC

* - These materials can be obtained at your local food store. Any brand/grade is acceptable

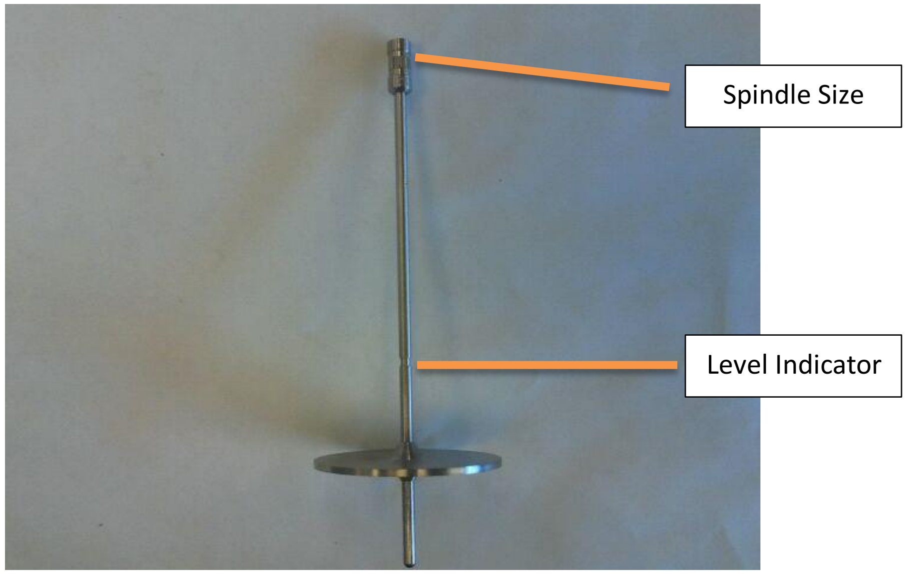
SAFETY CONDITIONS

Always wear safety glasses while in designated lab area. Wear gloves if necessary. Do not consume any food product unless the experiment is performed in a food lab using proper food safety protocols.

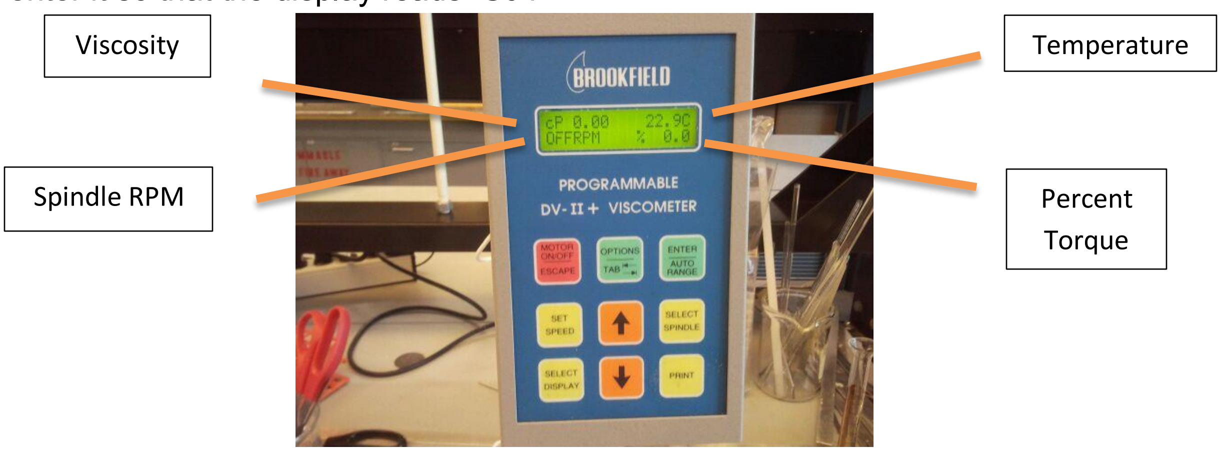
PROCEDURE

Commercial Salad Dressing Viscosity

1. Add 200 mL of salad dressing to the beaker
2. Remove any spindle attached to the viscometer
3. Turn on the viscometer and allow it to auto-zero
4. Select and attach the size 4 spindle to the viscometer (Note: The spindle size can be found at the top of the spindle shaft)



5. Place the beaker under the viscometer and lower the viscometer so that the liquid level of matches up to the level indicator on the spindle. Add more salad dressing if necessary
6. Press “Select Spindle” and then “↑” or “↓” and then “Select Spindle” again to enter it so that the display reads “S04”



7. Press “Motor ON/OFF” to start the motor
8. Adjust the rotations per minute (RPM) by pressing “↑” or “↓” then “Set Speed” to enter it at 100 RPM
9. Confirm that the torque % is between 10% and 100% for a valid measurement
10. Record the viscosity in centipoise (cP)
11. Put the temperature probe in the beaker and record the temperature of the solution. (Note: The temperature should be kept constant throughout the experiment)
12. Now use at least 5 different speed settings (RPM) and record the results. Note: The viscometer speed setting ranges from 0-100 RPM.
13. Press “Motor ON/OFF” to turn the motor off
14. Raise the viscometer spindle and thoroughly clean off equipment

Homemade Salad Dressing Preparation

1. Measure out the necessary materials from the formula below

Ingredient	**Volume (mL)**
Vegetable Oil	160
Vinegar	80
Corn Syrup	40
Tomato Paste	40
Water	10

2. Record the mass of each ingredient using a scale and a graduated cylinder in the results table provided in the RESULTS section
3. Combine materials in a food processor and blend until smooth and uniform throughout
4. Repeat steps in the previous procedure section to measure the viscosity of the mixture using a size 4 spindle at 100 RPM
5. Add 0.1 g of Xanthan gum to the mixture and blend
6. Measure the viscosity and record
7. Repeat steps 5 and 6, incrementally adding 0.1 g of xantham gum until the viscosity of the mixture can no longer be read by the size 4 spindle at 100 RPM

RESULTS

The tables below have been provided to help record the results of the experiment.

Material	Volume (mL)	Mass (g)	Mass Percent
Oil			
Vinegar			
Corn Syrup			
Tomato Paste			
Water			

Temp (°C)	Spindle Size	RPM	Torque (%)	Viscosity (cP)	Xanthan Gum (g)

INSTRUCTOR'S NOTE

Below are two sample tables with data.

Material	Volume (mL)	Mass (g)	Mass Percent
Oil	160	148.4	43.42
Vinegar	80	80.4	23.52
Corn Syrup	40	54.3	15.89
Tomato Paste	40	48.7	14.25
Water	10	10	2.93

Sample calculation for mass percent:

$$total\ mass = \sum component\ mass$$

$total\ mass = 148.4 + 80.4 + 54.3 + 48.7 + 10$ $\qquad total\ mass = 341.8\ g$

$mass\%\ oil = \frac{mass\ of\ oil}{total\ mass}$ $\qquad mass\%\ oil = \frac{148.4}{341.8}$ $\qquad mass\%\ oil = 43.42\%$

Temp (°C)	Spindle Size	RPM	Torque (%)	Viscosity (cP)	Xanthan Gum (g)
20.8	4	100	35.0	700	0
20.8	4	100	50.5	1006	0.1
21.4	4	100	65.4	1308	0.2
2`.7	4	100	86.3	1726	0.3
22.8	4	100	97.3	1944	0.4

DATA ANALYSIS

Import all data collected into Excel and create a plot with Xanthan gum mass concentration as the x-axis and viscosity as the y-axis. Add a trendline to the plot and display the equation and R-squared value.

QUESTIONS

1. Compare your observations before and after the xanthan gum was added. What did adding the xanthan gum do to the salad dressing?
   Ans: The color of the salad dressing before adding the xanthan gum was a deep red-orange color. After the xanthan gum is added, the dressing turns a brighter orange color. This is because adding the xanthan gum and mixing in a blender

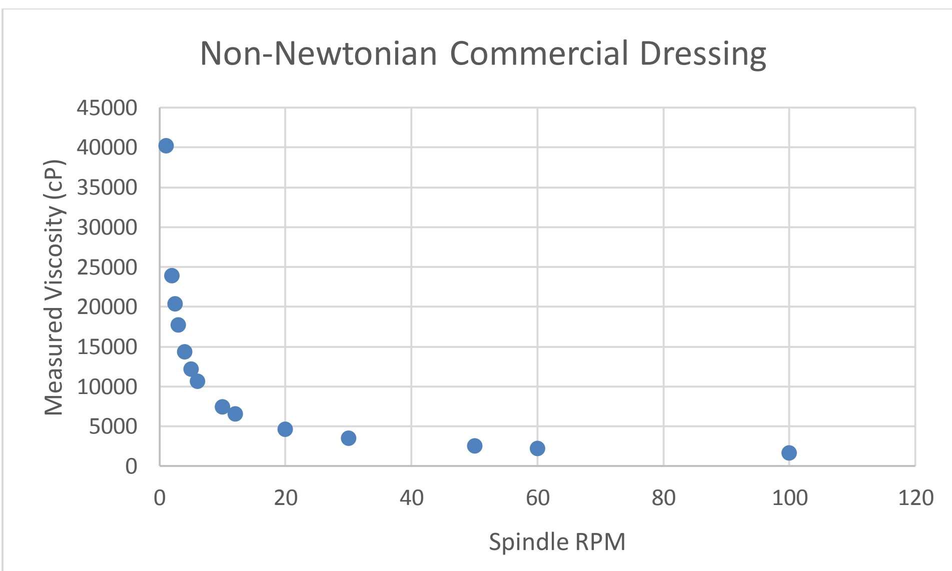
adds air to the salad dressing. The extra air bubbles give the salad dressing a slight color change.

2. Fluid viscosities can be categorized into two broad categories: Newtonian and non-Newtonian. Newtonian fluids have a direct, proportional relationship of shear stress (drag) to the change in velocity in the parallel direction of the shear stress. Non-Newtonian fluids do not have this direct, proportional relationship[4].

   The Brookfield viscometer works by measuring the drag force of the fluid on the spindle and displays a corresponding viscosity value[4]. The RPM controls how fast the spindle is moving through the fluid.

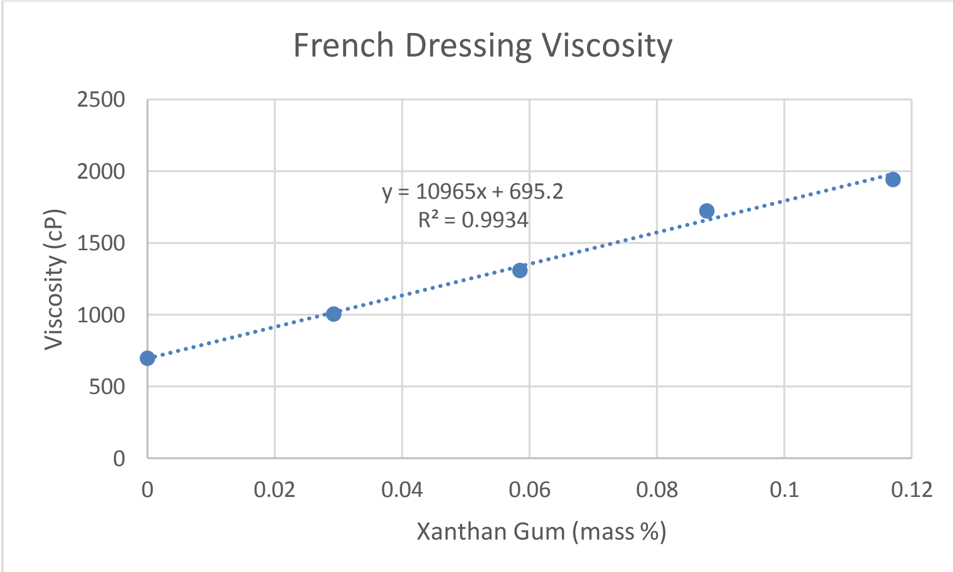
   Create a plot of the measured viscosity vs the spindle RPM using the data collected from step 12 of the Commercial Salad Dressing Viscosity procedure. Based on the information above and the resulting plot, do you think that salad dressing is a Newtonian or non-Newtonian fluid? Support your answer using observations and the data you collected.

   Ans: The salad dressing is a non-Newtonian fluid, which is why a constant spindle size and RPM must be used to compare viscosity readings. Increasing the RPM gives a lower viscosity reading and vice versa. This is shown in the plot below.



3. Using the Excel plot and trendline equation, what is the Xanthan gum concentration (mass %) in the commercial salad dressing?

   Ans:



$1624 = 10965x + 695.2$ $\qquad x = \frac{1624-695.2}{10965}$ $\qquad x = 0.0847\%$

The commercial French dressing had a viscosity of 1624 cP with a spindle size of 4 at 100RPM. Assuming a linear relationship between xanthan gum concentration and measured viscosity, the commercial salad dressing contains 0.085 % xanthan gum.

4. Besides increasing viscosity, what other properties does Xanthan gum contribute to the salad dressing? Be sure to cite your sources.
   Ans: Xanthan gum is used as a thickener, stabilizer, emulsifier, suspending agent, and bodying agent. It helps mix the oil and vinegar and keeps them form separating quickly on the shelf[5].

5. An intern is working for a Shale Oil Fracking company near Big State University. The required viscosity for drilling mud was recorded as 7250 lb/yd-hr by an intern who got decided to get creative with units. Help the intern to determine (a) what is the required viscosity in cP and (b) what is the required xanthan gum mass % of an oil and water based mud that behaves similarly to the salad dressing.
   Ans:

$$7250\frac{lb}{yd*hr}*1.0936\frac{yd}{m}*0.4536\frac{kg}{lb}*\frac{1}{3600}\frac{hr}{s}*\frac{1}{0.001}\frac{cP}{\frac{kg}{m}*s} = 999\ cP$$

Using the trendline equation:

$$999 = 10965 * x + 695.2$$
$$x = 2.78\ \%\ xanthan\ gum$$

6. Your superior culinary senses are telling you to add xanthan gum to your famous thick and smoky barbeque sauce, but you aren't sure how much to add. You want the barbeque sauce to be thick enough to stay on the food while it is grilling, but not so thick that the texture becomes undesirable. You decide you want the sauce to have twice the viscosity of commercial French dressing. Assuming the xanthan gum has the same effect on barbeque sauce as it has on salad dressing, how much xanthan gum would you need to add to your 500g batch of sauce?

   Ans: Target viscosity = 2*1624 = 3248 cP

   Using the trendline equation:

$$3248 = 10965 * x + 695.2$$
$$x = 0.23\ \%\ xanthan\ gum$$

$$Mass\ of\ xanthan\ gum = 500g * 0.0023 = 1.15g\ of\ xanthan\ gum$$

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