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chapter

Viscosity Measurements of Fluid Food Products

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26.1 INTRODUCTION

26.1.1 Background

Whether working in product development, quality control, or process design and scale-up, rheology plays an integral role in the manufacturing of high-quality food products. Rheology is a science based on fundamental physical relationships concerned with how all materials respond to applied forces or deformations. Flow behavior is one such response to force or deformation.

Determination and control of the flow properties of fluid foods are critical for optimizing processing conditions and obtaining the desired sensory qualities for the consumer. Transportation of fluids (pumping) from one location to another requires pumps, piping, and fittings such as valves, elbows, and tees. Proper sizing of this equipment depends on a number of elements but primarily on the flow properties of the product. For example, the equipment used to pump a dough mixture would be very different from that used for milk. Additionally, rheological properties are fundamental to many aspects of food safety. During continuous thermal processing of fluid foods, the amount of time the food is in the system (known as the residence time or RT), and therefore the amount of heating or "thermal dose" received, is directly related to its flow properties.

The rheological properties of a fluid are a function of composition, temperature, and other processing conditions, such as the speed the fluid travels through a pipe. Identifying how these parameters influence flow properties may be accomplished by measuring viscosity with a viscometer or rheometer. In this laboratory, we will measure the viscosity of two fluid foods using common rheological instruments widely used throughout the food industry. These instruments include a Brookfield rotational viscometer, a Zahn cup, and a Bostwick consistometer.

26.1.2 Reading Assignment

Joyner, H.S., and Daubert, C.R. 2017. Rheological principles for food analysis. Ch. 29, in *Food Analysis*, 5th ed. S.S. Nielsen (Ed.), Springer, New York.

Singh, R.P., and Heldman, D.R. 2001. *Introduction to Food Engineering*, 3rd ed., pp. 69–78, 144–157. Academic Press, San Diego, CA.

26.1.3 Objectives

1. Explain the basic principles of fluid rheology.
2. Gain experience measuring fluid viscosity using different equipment.
3. Describe the effects of temperature and (shear) speed on viscosity.

26.1.4 Supplies

- 6 beakers, 250 mL
- 3 beakers, 600 mL
- French salad dressing
- Honey (make sure there are no additional ingredients aside from honey)
- Thermometer or thermocouple with digital reader
- Stopwatch

26.1.5 Equipment

- Brookfield rotational viscometer model LV and spindle #3
- Brookfield Zahn cup #5 (hole diameter of at least 0.2 in)
- Bostwick consistometer
- Refrigerator

26.2 PROCEDURE

26.2.1 Brookfield Viscometer Measurements

1. Fill a 250 mL beaker with 200 mL honey and the two remaining 250 mL beakers with 200 mL salad dressing each. Label the beakers appropriately. Place one of the beakers of salad dressing in a refrigerator at least 1 h prior to analysis. The remaining beakers shall be allowed to equilibrate to room temperature.
2. Prior to evaluating the samples, make sure the viscometer is level. Use the leveling ball and circle on the viscometer to check.
3. On the data sheet provided, record the viscometer model number and spindle size, product information (type, brand, etc.), and the sample temperature. Because rheological properties are strongly dependent on temperature, sample temperatures must be measured and recorded prior to performing measurements.
4. Immerse the spindle into the test fluid (i.e., honey, salad dressing) up to the notch cut in the shaft. The viscometer motor should be off.
5. Zero the digital viscometers before turning on the motor.
6. Set the motor at the lowest speed revolutions per minute (rpm) setting. Once the digital display shows a stable value, record the percentage of full-scale torque reading. Increase the rpm setting to the next speed and again record the percentage of full-scale torque reading. Repeat this procedure until the maximum rpm setting has been reached or 100 % (but not higher) of the full-scale torque reading is obtained. *Do not increase the speed once 100 % of the full-scale torque has been reached.*

7. Stop the motor, then slowly raise the spindle from the sample. Remove the spindle and clean with soap and water, then dry. Be sure not to use any abrasive scrubbers or soaps on the spindle, as these can scratch the spindle and result in measurement errors.

8. Calculate the viscosity using the spindle factors. A factor exists for each spindle-speed combination (Table 26.1):
   For every dial reading (percentage full-scale torque), multiply the display value by the corresponding factor to calculate the viscosity with units of mPa-s.

   Example:
   A Ranch salad dressing was tested with a Brookfield LV viscometer equipped with spindle #3. At a speed of 6 rpm, the display read 40.6%. For these conditions, the viscosity is:

   $$\eta = (40.6)(200) = 8120\, mPa-s = 8012\, Pa-s$$

9. Repeat Steps 2–8 to test all samples.

10. Once all the data have been collected for the salad dressing and honey at room temperature, remove the salad dressing sample from the refrigerator, and repeat Steps 2–8. Be sure to record the sample temperature before performing any measurements.

11. You may choose to run the samples in duplicate or triplicate. Data from samples collected under identical conditions may be pooled to generate an average reading.

26.2.2 Zahn Cup Measurements

1. Fill a 600 mL beaker with 450 mL honey and the two remaining 600 mL beakers with 450 mL salad dressing each. The beakers must be tall enough so that the Zahn cup can be completely immersed in the sample. Label the beakers appropriately. Place one of the beakers of salad dressing in a refrigerator at least 2 h prior to

26.1
table   Factors for Brookfield model LV (spindle #3)

Speed (rpm)	Factor
0.3	4000
0.6	2000
1.5	800
3	400
6	200
12	100
30	40
60	20

analysis. The remaining beakers shall be allowed to equilibrate to room temperature.

2. On the data sheet provided, record the Zahn cup hole diameter and volume, product information (type, brand, etc.), and the sample temperature. Because rheological properties are strongly dependent on temperature, sample temperatures must be measured and recorded prior to performing measurements.

3. Completely immerse the Zahn cup into the test fluid (i.e., honey, salad dressing) so that the top of the cup is below the surface of the fluid. Allow the cup to fill with fluid. The cup must remain in the fluid for at least 5 min before measurements begin to equilibrate it to the sample temperature.

4. Put a finger through the ring at the top of the handle on the cup and lift it straight up out of the beaker. Start the stopwatch as soon as the top of the cup breaks the surface of the fluid.

5. Allow the cup to drain into the beaker with the bottom of the cup no more than six inches above the surface of the fluid.

6. Stop the stopwatch as soon as there is a clear break in the stream of fluid flowing out of the cup. Record the time at break, also called the Zahn time.

7. Clean the cup with soap and water, then dry. Be sure not to use any abrasive scrubbers or soaps on the cup, as these can scratch the cup and result in measurement errors.

8. Calculate the viscosity using the time conversion factors and the density of the test fluid. There are two conversion factors, K and C, to convert the Zahn time to viscosity in centistokes (cS) using the following equation:

$$\nu = K(t - C)$$

where:

   ν = kinematic viscosity (cS)
   t = Zahn time (s)

For a Brookfield Zahn Cup #5:

   $K = 23$
   $C = zero$

The kinematic viscosity can be converted to viscosity with units on mPa-s by multiplying by the specific gravity of the fluid. The specific gravities of honey and French dressing are approximately 1.42 and 1.10, respectively.

Example:
A Ranch salad dressing was tested with a #5 Brookfield Zahn cup. The stream broke at 80 s. Given that the specific gravity of the dressing is about 1.2, the viscosity is:

$$\eta = v(SG) = (K(t - C))(SG)$$
$$\eta = (23(80 - 0))(1.2) = 2208 \, mPa - s = 2.208 \, Pa - s$$

9. Repeat Steps 2–8 to test all samples.
10. Once all the data have been collected for the salad dressing and honey at room temperature, remove the salad dressing sample from the refrigerator, and repeat Steps 2–8. Be sure to record the sample temperature before performing any measurements.
11. You may choose to run the samples in duplicate or triplicate. Data from samples collected under identical conditions may be pooled to generate an average reading.

26.2.3 Bostwick Consistometer Measurements

1. Fill a 250 mL beaker with 200 mL honey and the two remaining 250 mL beakers with 200 mL salad dressing each. Label the beakers appropriately. Place one of the beakers of salad dressing in a refrigerator at least 1 h prior to analysis. The remaining beakers shall be allowed to equilibrate to room temperature.
2. Prior to evaluating the samples, make sure the consistometer is at the correct angle. Level the consistometer by adjusting the leveling screws under the consistometer until the leveling bubble is in the center of the black circle.
3. On the data sheet provided, record the consistometer make and model, product information (type, brand, etc.), and the sample temperature. Because rheological properties are strongly dependent on temperature, sample temperatures must be measured and recorded prior to performing measurements.
4. Close the product gate and hold it down while pulling the lever arm as far up as it can go.
5. Pour the test fluid (i.e., honey, salad dressing) in the product reservoir until it reaches the top of the product gate.
6. Push the lever arm down to raise the product gate; start the stopwatch as you push the lever arm down. Record the consistency or the distance the fluid traveled 30 s after the gate is raised. The numbers on the slope are distances in cm.
7. Clean the consistometer with soap and water, then dry. Be sure the consistometer is completely dry before using it again.
8. Repeat Steps 2–7 to test all samples.
9. Once all the data have been collected for the salad dressing and honey at room temperature, remove the salad dressing sample from the refrigerator, and repeat Steps 2–7. Be sure to

record the sample temperature before performing any measurements.
10. You may choose to run the samples in duplicate or triplicate. Data from samples collected under identical conditions may be pooled to generate an average reading.

26.3   DATA

26.3.1 Brookfield Viscometer

Date:
Product information:
Viscometer make and model:
Spindle size:

Sample	Sample temp (°C)	Spindle speed (rpm)	% Reading	Factor	Vicosity (mPa-s)

26.3.2 Zahn Cup

Date:
Product information:
Zahn cup hole diameter:
Zahn cup volume:

Sample	Sample temp (°C)	Zahn time (s)	Vicosity (cS)	Fluid density (kg/m³)	Vicosity (mPa-s)

26.3.3 Bostwick Consistometer

Date:
Product information:
Consistometer make and model:

Sample	Sample temp (°C)	Consistency (cm)

26.4   CALCULATIONS

26.4.1 Brookfield Viscometer

1. Sketch the experimental apparatus and label the major parts.
2. Calculate the viscosity of the test fluids at each rpm.
3. Plot viscosity versus rpm for each fluid on a single graph.
4. Label the plots with the type of fluid (e.g., Newtonian, pseudoplastic, Herschel-Bulkley)

based on the response of viscosity to speed (rpm). *Keep in mind that speed is proportional to shear rate. In other words, as the speed is doubled, the shear rate is doubled.*

26.4.2 Zahn Cup

1. Sketch the experimental apparatus and label the major parts.
2. Calculate the viscosity of the test fluids.
3. Compare the viscosity of the test fluids with the Zahn cup to the viscosities measured with the Brookfield viscometer. What speed in rpm would the Brookfield need to be run at for each fluid to match the viscosity measured using the Zahn cup?

26.4.3 Bostwick Consistometer

1. Sketch the experimental apparatus and label the major parts.
2. Compare the consistency of the test fluids with the consistometer to the viscosities measured with the Brookfield viscometer. Do the data match? What rpm gives you the best match?

26.5 QUESTIONS

1. What is viscosity?
2. What is a Newtonian fluid? What is a non-Newtonian fluid? Were your materials Newtonian or non-Newtonian? Explain your choice.
3. Describe the importance of viscosity and flow properties in food processing, quality control, and consumer satisfaction. How might food composition impact its viscosity or flow properties? What ingredient(s) in the salad dressing may have caused deviations from Newtonian behavior? What effect does temperature have on the viscosity of fluid foods?
4. For samples at similar temperatures and identical speeds, was the viscosity of honey ever less than the viscosity of salad dressing? Is this behavior representative of the sample rheology at all speeds?
5. Why is it important to test samples at more than 1 speed?

6. Compare the viscosities determined from the three different viscosity measurement methods. Are they similar? Do they give you the same information about the fluids? If there are differences in the viscosity results, what might be responsible for the differences?
7. Which viscosity measurement method gives you the most information about the test fluids? How could you adjust the other two measurement methods to give you more information about the test fluid?
8. Consistency is not the same as viscosity. Considering that different fluids have different flow behaviors, do you think it would be possible to develop an equation to convert consistency to viscosity? Why or why not?
9. A fluid food product was designed to have a certain viscosity profile. When the product was being developed, the viscosity was measured at several different speeds on a Brookfield viscometer. Now the product is in full-scale production in two locations. The quality control team in Location 1 uses a Zahn cup to check the viscosity of each batch of product. The quality control team at Location 2 uses a Bostwick consistometer to check the viscosity of each batch of product. What issues might occur if there is a problem with product viscosity at one of the production facilities or if the two production facilities want to compare product viscosity data?

RESOURCE MATERIALS

Joyner, HS, Daubert CR (2017) Rheological principles for food analysis. Ch 29. In: Nielsen SS (ed) Food analysis, 5th edn. Springer, New York

Singh RP, Heldman DR (2001) Introduction to food engineering, 3rd edn. Academic Press, San Diego, CA, pp 69–78, 144–157