Viscosity of Household Fluids

Wayne L. Elban
Department of Engineering
Loyola University Maryland
Baltimore, Maryland 21210

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ABSTRACT: A procedure is described for performing room temperature viscosity measurements on a variety of household fluids including new and used motor oils and kitchen and personal hygiene fluids. Data analysis was accomplished using a spreadsheet and accompanying plotting capability. The resultant plots allowed the fluids to be identified as exhibiting Newtonian or non-Newtonian behaviors and, if in the latter category, whether they were shear thinning or shear thickening.

KEY WORDS: Viscosity, rheology, Newtonian fluid, non-Newtonian fluid, shear thinning fluid, shear thickening fluid, Brookfield viscometer

PREREQUISITE KNOWLEDGE: Students should have an understanding of fluid viscosity and rheological behavior at the level available in an introductory materials science course (and accompanying laboratory course as needed). (Instructor Note 1)

OBJECTIVES:

(a) Experimental Goals:

1. To perform a calibration of a Brookfield viscometer using manufacturer-provided standard test fluids;
2. To measure the viscosity of a number of motor oils as a function of viscometer setting (rotational speed); and
3. To measure the viscosity of a number of kitchen and personal hygiene fluids as a function of viscometer setting (rotational speed).

(b) Learning Goals:

1. To be able to perform viscosity testing, a prominent technique for characterizing the flow properties/behaviors of fluid materials;
2. To be able to analyze the resultant viscosity data in order to assess rheological behavior;
3. To be able to identify Newtonian and non-Newtonian fluid behaviors; and
4. To be able to identify when shear thinning or shear thickening occurs in non-Newtonian fluids.
TYPE OF MODULE: Laboratory experiment

TIME REQUIRED: Viscosity measurements occur in two laboratory sessions each scheduled to last two hours and 40 minutes. (Instructor Note 1)

MODULE LEVEL: Intermediate; developed to be suitable as a sophomore-level undergraduate experience

MatEd CORE COMPETENCIES COVERED:

0.B Prepare tests and analyze data
1.A Carry out measurement of physical properties
2.B Demonstrate proper use of units and conversions
3.A Practice appropriate computer skills and uses
5.A Apply safe methods to chemical handling
6.A Apply basic concepts of mechanics
6.B Apply concepts of fluids
8.A Demonstrate the planning and execution of materials experiments
8.H Perform appropriate tests of liquids

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EQUIPMENT AND MATERIALS: (1) Brookfield viscometer (model RVDV-E) equipped with Spindles 02 to 07; (2) Brookfield Standard Fluids 500, 5000, and 60000; (3) various new and used motor oils; (4) various kitchen and personal hygiene fluids; (5) pint regular mouth glass canning jars; (6) Ball regular mouth reusable plastic storage caps; (7) Kimwipes; (8) mineral spirits. (Instructor Note 2)
SAFETY PRECAUTIONS: The necessary safety precautions are provided in the EXPERIMENTAL sections that follow. In addition, care must be taken to avoid moving the sample once the viscometer commences its operating cycle.

INTRODUCTION:

General Background: When crystalline materials are subjected to stress, the material will initially deform elastically and as the stress increases, plastically. This plastic deformation occurs mostly by slipping which involves dislocation movement or sometimes by mechanical twinning. The deformation of amorphous liquids (or particulate solid-liquid mixtures, called slurries) on the other hand is best characterized by a material property known as viscosity. Viscosity is a measure of a fluid’s resistance to flow. [1] For fluid flowing in parallel layers (known as laminar flow). Newton used viscosity, \( \eta \), to relate the shear stress, \( \tau \), experienced by the fluid and the velocity gradient for one-dimensional flow, \( \frac{dv}{dx} \), as

\[
\tau = \eta \left( \frac{dv}{dx} \right).
\]

This is known as Newton’s Law of Viscosity where \( x \) represents a coordinate that is normal to the flow direction at the location in question within the moving fluid. The dimensions of \( \eta \) are those of \((\text{shear stress} / \text{velocity gradient})\) or \((\text{force/area}) / (\text{velocity/length}) = (\text{force})(\text{time}) / \text{area} = \text{FT/L}^2\).

The usual units for viscosity are given in some multiple of poise, \( P \) [= 1 dyne\( \cdot \)s/cm\(^2\) (using cgs units)].

In Shackelford [2] for example, viscosity is introduced as a material property to describe the deformation behavior and processing conditions of soda-lime-silica glass (Fig. 6.43) where a large decrease in viscosity is observed with increasing temperature. Although not extensively covered in many introductory materials science textbooks, viscosity is similarly used to characterize a wide variety of other materials often encountered in everyday life such as adhesives, caulks, paints, lacquers, lubricants (oils and greases), foods, personal care items, polymer resins, and polymer-based particulate pre-cured composites. [3] Viscosity is an important parameter used to establish proper processing and end-use conditions for all of these types of materials.

The Brookfield viscometer is a highly versatile instrument widely used to measure the viscosity of a large variety of fluids. The instrument rotates, at a fixed speed, a spindle that is immersed in the test fluid to a fixed depth that is indicated on the spindle shaft. A variety of spindles (e.g., numbered 01 to 07) are available having progressively smaller diameters allowing fluids with a large range in viscosity (100 to 13\( \times \)10\(^6\) cP) to be characterized. Between the spindle and the motor is a calibrated spiral spring whose deflection is related to the viscous drag of the fluid on the spindle. Increasing both rotational speed and spindle size causes an increase in viscous drag. Varying the rotational speed for a given spindle allows the rheological behavior of the fluid to be assessed. The particular instrument used in this experiment has a digital display and is very easy to use.
With two exceptions (Spindle 01, which is cup-shaped, and Spindle 07, which is simply a rod), the spindle attached to the operating viscometer may be modeled as a thin disk immersed and rotating in a fluid of sufficient extent or volume that container wall effects are eliminated. Further, the areas of the cylindrical surface of the disk and the portion of the shaft holding the disk that is immersed in the fluid are considered to provide a very small contribution compared to the areas of the top and bottom surfaces of the disk. With these idealizations, the torque, \( M \), is given \([4,5]\) by

\[
M = \frac{32}{3} R^3 \Omega \eta, \quad (3)
\]

where \( R \) = radius of the disk, and

\( \Omega = \) angular velocity = \( \frac{2\pi \text{ (rotational speed in units of RPM) / 60}}{\text{ rad/s}} \).

Using the \( \eta \) measured for the rotational speed set by the viscometer, the average shear stress, \( \tau_{av} \), imposed on the fluid by the rotating disk is calculated using

\[
\tau_{av} = \frac{3M}{4\pi R^3} = \frac{(8/\pi)}{\Omega \eta}, \quad (4)
\]

and the corresponding average shear rate, \( q_{av} \), is computed using

\[
q_{av} = \frac{(8/\pi)}{\Omega}. \quad (5)
\]

**Current Work:** The purpose of this experiment is to measure the viscosity of a number of items typically found around the house as a function of spindle speed using a commercial rotational viscometer (Brookfield) and to determine whether they exhibit Newtonian or non-Newtonian behaviors. \([6]\) (Instructor Note 3) In Week 1, a series of motor oils will be evaluated; a number of different weight oils either as-purchased new or recovered from several different gasoline engines will be evaluated. In Week 2, a number of kitchen and personal hygiene fluids will be similarly characterized.

**Week 1**

**Newtonian liquids \([6]\):** Simple liquids like water are classified as being Newtonian when Eq. (1) describes their behavior. For a disk rotating in a Newtonian liquid at constant temperature, a plot of \( \tau_{av} \) as a function of \( q_{av} \) yields a straight line having a slope \( \eta \) which is not dependent on \( q_{av} \).

In the lab exercises described below, each team (lab group) of 3-4 students is to obtain their own results to be shared just within the group.

**PROCEDURE:**

A. EXPERIMENTAL

Record measurements and any relevant observations in a laboratory notebook with appropriate drawings.
Viscosity measurements on various motor oils at room temperature:

(1) Carefully attach Spindle 02 to the viscometer. Note: this involves left-hand threads so you turn counter clockwise to tighten the spindle; tightening should occur very easily, so don’t force it as you are probably cross-threading.

(2) Perform a calibration of the viscometer using the Standard Fluid 500 (\(\eta = 510 \text{ cP at 25.0}^\circ\text{C}\)) contained in the as-provided jar for all permissible rotational speeds starting at 10 RPM. (Instructor Note 4) Note: the display will be flashing whenever the measured viscosity is <10\% of full scale; these measurements should be recorded in your notebook but not used in the data analysis and plotting exercises. Particularly at low rotational speeds, it is also important to allow sufficient time for a steady flow condition to develop corresponding to when the display stops flashing. Once these measurements are completed, the spindle is lifted out of the fluid and allowed to drain until finished; after carefully detaching the spindle from the viscometer, thoroughly clean the spindle by first wiping off the excess as much as possible with a Kimwipe and then rinsing with mineral spirits in the fume hood and finally drying with a Kimwipe.

To follow safe handling practice while cleaning the spindle, either latex or nitrile disposable gloves must be used.

(3) Carefully reattach the spindle specified below to the viscometer and measure the viscosity of the following motor oils as a function of rotational speed. Before lowering the spindle into the next motor oil, be sure to follow the cleaning steps given with the above calibration procedure to avoid cross contamination.

Motor oils (petroleum-based and unused unless otherwise designated) contained in pint regular mouth glass canning jars to be tested upscale (rotational speed increased systematically) using the designated spindle(s) are:

(a) Duralene Dura-Tech SAE 10W30 (Spindle 02);

(b) Valvoline Full Synthetic SAE 10W30 (Spindle 02);

(c) Duralene Dura-Tech SAE 10W30 (used: ~ 3000 miles in 1992 Buick Century) (Spindle 02);

(d) SAE 10W40 NAPA Premium (Spindle 02 and Spindle 03);

(e) SAE 10W40 NAPA High Milage (Spindle 03);

(f) SAE 10W40 Valvoline Motorcycle 4-Stroke (Spindle 03);

(g) SAE 10W40 NAPA Premium (used: ~ 3000 miles in 1998 Dodge Dakota) (Spindle 02 and Spindle 03);
B. ANALYSIS

For the various motor oils characterized, use Excel (or equivalent) to prepare plots as necessary of (1) viscosity as a function of spindle rotational speed and (2) average shear stress, $\tau_{av}$, as a function of average shear rate, $q_{av}$, in order to respond to the following requests/questions in sentence format as completely as possible, being sure to give all of your reasoning as partial credit can be earned. The latter plot will necessitate performing unit conversions to obtain $\tau_{av}$, in units of Pa and $q_{av}$, in units of s$^{-1}$. Analysis of the first set of data with accompanying plots can be used as a template to work on the remaining data sets in an expeditious manner.

(1) For the valid viscosity-rotational speed measurements obtained for Standard Fluid 500, use Eq. (4) to calculate the average shear stress, $\tau_{av}$, in units of Pa, and similarly use Eq. (5) to calculate the average shear rate, $q_{av}$, in units of s$^{-1}$. The following unit conversion factors will prove helpful: (a) 1 min = 60 s and (b) 1 Pa⋅s = 1000 cP. (Instructor Note 5) Prepare a plot of $\tau_{av}$ as a function of $q_{av}$ and perform a least-squares fit analysis (Excel trendline) to determine the viscosity and report the value in units of cP. Note that the point (0,0) should be included in this analysis. Discuss how this viscosity compares with the value supplied with the standard fluid and hence how well the viscometer is performing. Determine whether this fluid is Newtonian or non-Newtonian and give your reasoning.

(2) Using the valid viscosity-rotational speed measurements and appropriate plots, compare the behaviors of the following sets of motor oils:

a. petroleum and synthetic SAE 10W30 motor oils;

b. new and used petroleum SAE 10W30 motor oils;

c. new and used petroleum SAE 10W40 motor oils;

d. new and used petroleum SAE 30 motor oils; and

e. petroleum SAE NAPA Premium, NAPA High Mileage, and Valvoline Motorcycle 4-stroke 10W40 motor oils.

For each of these sets of oils, ascertain what hierarchy (ordering from highest to lowest viscosity) exists and whether the oils exhibit Newtonian or non-Newtonian behaviors and provide your reasoning.
If the oil is Newtonian, determine its viscosity in units of cP by performing a least-squares fit analysis of the values appearing in the plot of \( \tau_{av} \) as a function of \( q_{av} \).

Week 2

Non-Newtonian fluids [6,7,12]: Many fluids do not exhibit constant \( \eta \) as a function of shear rate. Some are termed “shear thinning” or “pseudoplastic” because as the first name suggests \( \eta \) decreases with increasing shear rate, while others are called “shear thickening” or “dilatant” because \( \eta \) increases as shear rate increases. For a thin disk rotating in a non-Newtonian fluid, a plot of \( \tau_{av} \) as a function of \( q_{av} \) does not yield a straight line.

Many industrially important fluids are classified as non-Newtonian, and their behaviors cannot be adequately described by Eq. (1). However, the behaviors of these fluids subjected to a rotating disk can be described using a generalized form of Eq. (1) as

\[
J_{av} = \eta[f(q_{av})] q_{av},
\]

where now \( \eta \) is a function of the average shear rate.

In the lab exercises that follow, each team (lab group) of 3-4 students is to obtain their own results to be shared just within the group.

PROCEDURE:

A. EXPERIMENTAL

Record all of your measurements and any observations with drawings as appropriate in your notebook.

Viscosity measurements on various kitchen and personal hygiene fluids at room temperature:

1. Carefully attach Spindle 05 to the viscometer. (Reminder from Week 1: This involves left-hand threads so you turn counter clockwise to tighten the spindle; tightening should occur very easily, so don’t force it as you are probably cross-threading.)

2. Perform a calibration of the viscometer using the Standard Fluid 5000 (\( \eta = 4900 \) cP at \( 25.0^\circ \) C) provided for all permissible rotational speeds starting at 6 RPM. (Reminder from Week 1: The display will be flashing whenever the measured viscosity is <10% of full scale; these measurements should be recorded in your notebook but not used in the data analysis and plotting exercises. Particularly at low rotational speeds, it is also important to allow sufficient time for a steady-flow condition to develop corresponding to when the display stops flashing. Once these measurements are completed, the spindle is lifted out of the fluid and allowed to drain until finished; after carefully detaching the spindle from the viscometer, thoroughly clean the spindle by first wiping off the excess as much as possible with a Kimwipe and then rinsing with mineral spirits in the fume hood and finally drying with a Kimwipe.)
To follow safe handling practice while actually cleaning the spindle, either latex or nitrile disposable gloves must be used.

(3) Carefully attach Spindle 07 to the Brookfield viscometer.

(4) Perform a calibration of the viscometer using the Standard Fluid 60000 ($\eta = 58560$ cP at $25.0^\circ$ C) provided for all permissible rotational speeds starting at 6 RPM.

(5) Carefully reattach the spindle specified below to the viscometer and measure the viscosity of the following household fluids as a function of rotational speed. (Reminder from Week 1: Before lowering the spindle into the next fluid, be sure to follow the cleaning steps given with the above calibration procedure to avoid cross contamination.)

Household fluids contained in pint regular mouth glass canning jars to be tested upscale using the designated spindle(s) are:

(a) Dawn Original Scent Dishwashing Liquid (Spindle 02);

(b) Golden Barrel Supreme Baking Molasses (Spindle 06);

(c) Weis Creamy Peanut Butter (Spindle 07) -- also subsequently test downscale (rotational speed decreased systematically);

(d) Pert Plus 2-in-1 Shampoo and Conditioner (Spindle 04);

(e) L.A. Looks Absolute Styling Gel (Spindle 07) -- also subsequently test downscale; and

(f) Weis Corn Starch - Water Suspension (Spindle 02) -- this material (400 ml corn starch stirred into 200 ml water) must be prepared before testing can proceed. (Instructor Note 6)

B. ANALYSIS

For the various household fluids characterized, use Excel (or equivalent) to prepare plots of (1) viscosity as a function of spindle rotational speed and (2) average shear stress, $\tau_{av}$, as a function of average shear rate, $q_{av}$, in order to respond to the following requests/questions in sentence format as completely as possible, being sure to give all of your reasoning as partial credit can be earned.

(1) For the valid viscosity-rotational speed measurements obtained for Standard Fluid 5000, perform the same analysis followed previously for Standard Fluid 500 (Week 1). Discuss how this viscosity compares with the value supplied with the standard fluid and hence how well the viscometer is performing. Determine whether this fluid is Newtonian or non-Newtonian and give your reasoning.
(2) Repeat the analysis procedure for Standard Fluid 60000. Discuss how this viscosity compares with the value supplied with the standard fluid and hence how well the viscometer is performing. Determine whether this fluid is Newtonian or non-Newtonian and give your reasoning.

(3) Using the valid viscosity-rotational speed measurements for the six (6) kitchen and personal hygiene fluids, ascertain whether they exhibit Newtonian or non-Newtonian behavior and provide your reasoning.

If the fluid is Newtonian, determine its viscosity by performing a least-squares fit analysis of the values appearing in the plot of $\tau_{av}$ as a function of $q_{av}$.

If the fluid is non-Newtonian, ascertain whether the fluid is shear thinning or shear thickening and provide your reasoning.

(4) Using the valid viscosity-rotational speed upscale and downscale measurements obtained for Weis Creamy Peanut Butter and for L.A. Looks Absolute Styling Gel, prepare separate plots of viscosity, $\eta$, in units of cP, as a function of rotational speed in units of RPM. Compare the behaviors for the measurements taken in opposite directions.

**COMMENTS with Sample Data (Selected) and Plots:**

The data appearing in this section are considered to be representative; some of the data were repeated, and all have been verified by students when they performed this experiment in Spring 2014.

**Standard fluid testing:** Using the conversion factors provided, the average shear stresses and average shear rates were calculated and appear in Table 1 for Standard Fluid 500 for the measured viscosity values obtained at varying rotational speeds. The resultant plot (Figure 1) is highly linear with a slope of 0.546 Pa∙s (546 cP) obtained for a temperature of 22.1°C which compares favorably with the calibration value of 510 cP given for 25.0°C since viscosity increases with decreasing temperature. Similar findings were obtained for Standard Fluids 5000 and 60000; referring to Figure 7, the viscosities of these fluids are 5180 cP (T= 24.0°C) and 58400 cP (T = 23.9°C), respectively, to be compared with corresponding calibration values of 4900 cP and 58560 cP obtained at 25.0°C.

**Motor oil testing:** The plots of average shear stress as a function of average shear rate for all of the motor oil samples were highly linear indicating Newtonian behavior throughout which is consistent with the results for a variety of multi-grade motor oils obtained by other researchers [8]. The viscosity of petroleum SAE 10W30 oil was 9.4% higher than its synthetic counterpart. (Figure 2) In the three instances where unused and used petroleum oils were compared, the viscosity of the used oils decreased 7.9%, 6.1%, and 16.2% for the SAE 10W30, SAE 30, and SAE10W40 oils, respectively. (Figures 3 to 5). The hierarchy of viscosities for the three types of unused SAE 10W40 oils revealed Valvoline Motorcycle oil > NAPA High Mileage oil > NAPA Premium with only small differences being observed. (Figure 6) Table 2 summarizes the
viscosity results obtained for the motor oils that were characterized. There is reasonable agreement between the viscosity value for SAE 30 motor oil (231 cP) and the reported range of values (150-200 cP) [6].

Kitchen and personal hygiene fluid testing: The dishwashing liquid and molasses both exhibited Newtonian behaviors with viscosities of 396 and 5420 cP, respectively. (Figures 8 and 9) The peanut butter, shampoo/conditioner, and styling gel all displayed non-Newtonian (shear thinning behaviors) with the styling gel being the most pronounced. (Figures 10 to 12). The behavior of the corn starch - water suspension was also non-Newtonian but strongly shear thickening which is consistent with the findings of other researchers [9,10]. (Figure 13) A significant difference was found for the upscale versus downscale measurements obtained for creamy peanut butter with the downscale values being below the upscale readings except that taken at 1 RPM. (Figure 14) In comparison, a minimal difference was obtained for the styling gel when the measurement direction was reversed. (Figure 15) A summary of the viscosity results appears in Table 3 for the kitchen and personal hygiene fluids that were characterized. The viscosity value for molasses compares favorably with the reported range of values (5000-10000 cP, respectively) [6].

Uncertainty analysis/source of error: The accuracy of the torque measurements stated by the manufacturer is 1% full scale.[11] As an example, accuracy values are provided in the fourth column of Table 1 for Standard Fluid 500. The repeatability given by the manufacturer is 0.2 % full scale.[11] The most significant sources of human error were not immersing the spindle to the proper depth in the fluid to be tested and recording viscosity values before steady fluid flow was established.

INSTRUCTOR NOTES:

1. The viscosity measurements described in this experiment can be accomplished during two (2) 160 minutes laboratory periods held on consecutive weeks. Analysis and interpretation of the results were performed outside of class, although there was sufficient time in lab for discussion. Students gained familiarity with the concept of fluid viscosity and its measurement and different fluid behaviors in an introductory lecture lasting about 20 minutes prior to commencing laboratory work in the first week.

2. Recommended practice is to obtain measurements on a fluid tested in a container having a minimum inside diameter ≥ 83 mm, and a 600 mL low form Griffin beaker is specified.[12] However to facilitate fluid handling and clean-up, the Standard Fluids were tested in the jars they were shipped in, while all of the household fluids were tested in regular mouth glass canning jars (nominal inside diameter = 74 mm and fluid height = 75 mm, corresponding to being several millimeters below where the jar neck commences). In a side study using Spindle 03, very small differences in viscosity values (558, 560, and 553 cP) were obtained for Standard Fluid 500 tested in its shipping jar (T = 20.8° C), the regular mouth glass canning jar (T = 20.5° C), and the 600 mL low form Griffin beaker (T = 20.5° C), respectively. While a container wall effect may be present in measurements taken on some of the household fluids, thus contributing to the viscosity uncertainty, each fluid tested does exhibit the expected rheological behavior.
3. The current viscosity experiment relates to several previous National Educators' Workshop papers [13-15] on various aspects of viscosity determination.

4. Recommended practice does not consider displayed viscosity values valid when the displayed % Full Scale (Torque) is < 10%, and they are to be discarded. It is not possible to obtain viscosity measurements for % Full Scale readings > 100%, and this is indicated on the digital display.[16]

5. Alternatively, it can be left to the student to obtain the necessary unit conversion factors from the internet for example.[17]

6. Prior to mixing, 400 mL corn starch and 200 mL deionized water are placed in separate clean 600 mL low form Griffin beakers. The water is then transferred in a clean 900 mL plastic container, and the corn starch is slowly added (by one student) and stirred (by a second student also firmly holding the plastic container) into the water using a wooden paint stirrer; care must be taken to stir continuously while the corn starch is being added and not to pour the corn starch too quickly, either of which make creating a well-mixed suspension very difficult. **To follow safe handling practice, each student must wear a dust mask during any operation that involves exposure to dry corn starch while creating the suspension; once all of the corn starch is added, wetted by water, and well mixed, the dust masks may be removed in order to perform viscosity measurements.**

REFERENCES:


**SOURCES OF SUPPLIES:** The viscometer is available from Brookfield Engineering Laboratories, Inc., 11 Commerce Boulevard, Middleboro, MA 02346; phone (800-628-8139); FAX (508-946-6262); Web site (www.brookfieldengineering.com). Standard Fluids are also available from Brookfield Engineering Laboratories, Inc. The materials tested (or similar materials) can be purchased at local auto parts stores, grocery stores, or drug stores as appropriate.

**ACKNOWLEDGEMENTS:** Dr. Robert T. Bailey, Department of Engineering, Loyola University Maryland, offered insightful comments about the analysis model and equations used to calculate the shear stress-shear strain results that were obtained and helpful suggestions about the manuscript. The identification of any manufacturer and/or product does not imply endorsement or criticism by the author or Loyola University Maryland.

**ABOUT THE AUTHOR:**

Wayne L. Elban

Since 1985, Professor Elban has taught engineering courses at Loyola College (now Loyola University Maryland), including introductory materials science, materials science lab, mechanical properties of materials, transformations in solids, and engineering materials and manufacturing processes. He received a BChE with distinction (’69) and a PhD in Applied Sciences: Metallurgy (’77) from the University of Delaware and a MS in Engineering Materials (’72) from the University of Maryland, College Park. From 1969-1985, he was a research engineer at the Naval Surface Warfare Center, White Oak Laboratory, Silver Spring, Maryland. In 1992, he was a Fulbright scholar at the University of Strathclyde (Glasgow), Department of Pure and Applied Chemistry. From 2001-2003, he was a working visitor at the Smithsonian Center for Materials Research and Education, Silver Hill, Maryland. From 2008-2011, he was a guest worker at the National Institute of Standards and Technology, Gaithersburg, Maryland. He is a member of ASM International and the Society of Manufacturing Engineers.
Table 1. Viscosity measurements obtained at various rotational speed settings for Brookfield Standard Fluid 500 with corresponding calculated shear stress and shear rate values. (T = 22.1° C)

<table>
<thead>
<tr>
<th>Rotational Speed, RPM</th>
<th>Viscosity, cP</th>
<th>% Full Scale (FS)</th>
<th>Accuracy, ± 0.01FS</th>
<th>Shear Rate, 1/s</th>
<th>Shear Stress, Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>548</td>
<td>13.7</td>
<td>40.0</td>
<td>2.67</td>
<td>1.46</td>
</tr>
<tr>
<td>10</td>
<td>547</td>
<td>16.4</td>
<td>33.4</td>
<td>3.20</td>
<td>1.75</td>
</tr>
<tr>
<td>20</td>
<td>546</td>
<td>27.3</td>
<td>20.0</td>
<td>5.33</td>
<td>2.91</td>
</tr>
<tr>
<td>30</td>
<td>544</td>
<td>40.8</td>
<td>13.3</td>
<td>8.00</td>
<td>4.35</td>
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<tr>
<td>50</td>
<td>546</td>
<td>68.2</td>
<td>8.0</td>
<td>13.33</td>
<td>7.27</td>
</tr>
<tr>
<td>60</td>
<td>547</td>
<td>82.0</td>
<td>6.7</td>
<td>16.00</td>
<td>8.75</td>
</tr>
</tbody>
</table>

Figure 1. Brookfield Standard Fluid 500 exhibiting Newtonian behavior with a viscosity of 0.546 Pa·s (546 cP) at 22.1° C.
Figure 2. Comparison of petroleum and fully synthetic SAE 10W30 motor oils, both exhibiting Newtonian behaviors with viscosities of 0.163 Pa·s (163 cP) and 0.149 Pa·s (149 cP), respectively.

Figure 3. Comparison of unused and used petroleum SAE 10W30 motor oils, both exhibiting Newtonian behaviors with viscosities of 0.164 Pa·s (164 cP) and 0.151 Pa·s (151 cP), respectively.
Figure 4. Comparison of unused and used petroleum SAE 10W40 motor oils, both exhibiting Newtonian behaviors with viscosities of 0.215 Pa·s (215 cP) and 0.180 Pa·s (180 cP), respectively.

Figure 5. Comparison of unused and used petroleum SAE 30 motor oils, both exhibiting Newtonian behaviors with viscosities of 0.231 Pa·s (231 cP) and 0.217 Pa·s (217 cP), respectively.
Figure 6. Comparison of three types of petroleum SAE 10W40 motor oils, all exhibiting Newtonian behaviors with viscosities of 0.229 Pa·s (229 cP), 0.220 Pa·s (220 cP), and 0.214 Pa·s (214 cP), respectively.

Table 2. Compilation of viscosity results for various motor oils.

<table>
<thead>
<tr>
<th>Oil Designation</th>
<th>Weight</th>
<th>Condition</th>
<th>Viscosity, cP</th>
<th>Rheological Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duralene Dura-Tech</td>
<td>10W30</td>
<td>Unused</td>
<td>163-164</td>
<td>Newtonian</td>
</tr>
<tr>
<td>Valvoline Full Synthetic</td>
<td>10W30</td>
<td>Unused</td>
<td>149</td>
<td>Newtonian</td>
</tr>
<tr>
<td>Duralene Dura-Tech</td>
<td>10W30</td>
<td>Used</td>
<td>151</td>
<td>Newtonian</td>
</tr>
<tr>
<td>NAPA Premium</td>
<td>10W40</td>
<td>Unused</td>
<td>214-215</td>
<td>Newtonian</td>
</tr>
<tr>
<td>NAPA Premium</td>
<td>10W40</td>
<td>Used</td>
<td>180</td>
<td>Newtonian</td>
</tr>
<tr>
<td>Duralene Dura-Guard</td>
<td>30</td>
<td>Unused</td>
<td>231</td>
<td>Newtonian</td>
</tr>
<tr>
<td>Duralene Dura-Guard</td>
<td>30</td>
<td>Used</td>
<td>217</td>
<td>Newtonian</td>
</tr>
<tr>
<td>NAPA High Mileage</td>
<td>10W40</td>
<td>Unused</td>
<td>220</td>
<td>Newtonian</td>
</tr>
<tr>
<td>Valvoline Motorcycle</td>
<td>10W40</td>
<td>Unused</td>
<td>229</td>
<td>Newtonian</td>
</tr>
</tbody>
</table>
Figure 7. Brookfield Standard Fluids 5000 and 60000 exhibiting Newtonian behaviors with viscosities of 5.18 Pa·s (5180 cP) and 58.4 Pa·s (58400 cP), respectively.

Figure 8. Dawn Original Scent Dishwashing Liquid exhibiting Newtonian behavior with a viscosity of 0.396 Pa·s (396 cP).
Figure 9. Golden Barrel Supreme Baking Molasses exhibiting Newtonian behavior with a viscosity of 5.42 Pa·s (5420 cP).

Figure 10. Weis creamy peanut butter exhibiting non-Newtonian behavior (shear thinning).
Figure 11. Pert Plus 2-in-1 Shampoo and Conditioner exhibiting non-Newtonian behavior (shear thinning).

Figure 12. L.A. Looks Absolute Styling Gel (Sport Mega X-treme Hold 10+) exhibiting non-Newtonian behavior (shear thinning).
Figure 13. Weis corn starch - water (400 mL - 200 mL) exhibiting non-Newtonian behavior (shear thickening).

Figure 14. Weis creamy peanut butter exhibiting separation in the upscale and downscale measurements.
Figure 15. L.A. Looks Absolute Styling Gel (Sport Mega X-treme Hold 10+) exhibiting nearly identical upscale and downscale measurements.

Table 3. Compilation of viscosity results for various kitchen and personal hygiene fluids.

<table>
<thead>
<tr>
<th>Fluid Designation</th>
<th>Rheological Behavior</th>
<th>Viscosity, cP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dawn Original Scent Dishwashing Liquid</td>
<td>Newtonian</td>
<td>396</td>
</tr>
<tr>
<td>Golden Barrel Supreme Baking Molasses</td>
<td>Newtonian</td>
<td>5420</td>
</tr>
<tr>
<td>Weis creamy peanut butter</td>
<td>Non-Newtonian; Shear Thinning</td>
<td>f (shear rate)</td>
</tr>
<tr>
<td>Pert Plus 2-in-1 Shampoo &amp; Conditioner</td>
<td>Non-Newtonian; Shear Thinning</td>
<td>f (shear rate)</td>
</tr>
<tr>
<td>L.A. Looks Absolute Styling Gel</td>
<td>Non-Newtonian; Shear Thinning</td>
<td>f (shear rate)</td>
</tr>
<tr>
<td>Weis corn starch - water (400 mL - 200 mL)</td>
<td>Non-Newtonian; Shear Thickening</td>
<td>f (shear rate)</td>
</tr>
</tbody>
</table>
EVALUATION PACKET:

Student evaluation questions (discussion or quiz):

1. Define viscosity and give Newton’s Law of Viscosity, identifying all of its parameters.
2. Considering the fluids encountered where you live, give examples of materials with low and high viscosities.
3. Discuss why it is important to test standard fluids with the viscometer before testing materials with unknown viscosities.
4. Discuss the defining characteristics of a Newtonian fluid.
5. Discuss the defining characteristics of a non-Newtonian fluid
6. Discuss the defining characteristics of shear thinning and shear thickening fluids.

Instructor evaluation questions:

1. At what educational level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the lab work as presented? Did it add to student learning? Please note any problems or suggestions.
4. Was the background material provided sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the lab generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus, and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the lab write-up clear and understandable?
2. Was the instructor’s explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of measuring viscosity and characterizing rheological behavior of fluids made clear?
6. What was the most interesting thing that you learned?