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Viscosity as a function of Temperature with *micro*VISC™

*micro*VISC™: Temperature Dependent Viscosity Study

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Objective: This study was carried out to determine the viability of using the RheoSense *micro*VISC™ to record temperature dependent viscosity data using various solutions of water and corn syrup at three temperatures. The collected data followed trends seen in similar studies analyzing viscosity of various syrups.

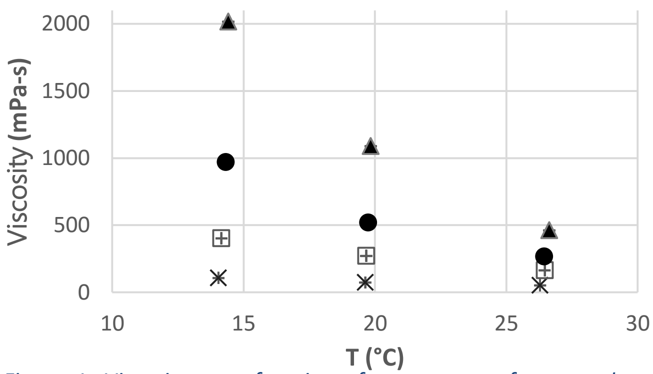

Figure 1. Viscosity as a function of temperature for several syrup concentrations. Percentages v/v water/corn syrup: x: 30%, □: 20%, ●: 15%. ▲:10%.

Materials: Distilled water used in these experiments came from the commercial brand Nice!. The syrup used was Light Corn Syrup from Kroger Foods. 70% isopropyl alcohol from CVS was used to clean the viscometer. The viscometer used was RheoSense *micro*VISC™ (HVROC-L). The cartridge on the viscometer was a VROC® chip (HA02-01). The software used to analyze data was Microsoft Excel 2013.

BENEFITS OF *micro*VISC™ + TC SOLUTION

*micro*VISC™ uses RheoSense's Viscometer-Rheometer-on-a-Chip (VROC®) technology to offer high accuracy and repeatability which makes them ideal for R&D and QC applications.

Features include:

- Accuracy: 2% of reading.
- Repeatability: 0.5% of reading.
- Small sample volume.
- Shear Viscosity range: 0.2 – 20,000 mPa-s.
- Shear Rate range: 1.7 -5,800 s^{-1}
- Temperature control: 18-50°C

Procedure: To test the viscometer, nine 10 mL solutions of distilled water and corn syrup were prepared on volume per volume basis ranging between 100% distilled water to 10% distilled water. Solutions were prepared with 3 mL syringes. Viscosity measurements were taken in three different environments where the room temperature averaged 13.8, 19.6, and 26.5 °C. The experiments were carried out on different days and new sets of solutions were prepared for each of the three temperatures.

Measurement Protocol:

Loading...	Measuring...	Cleaning...
		
Load your sample into one of *micro*VISC® disposable pipettes. Place it in the system and you are ready!	Perform a quick automatic measurement or run at several shear rates using advanced mode.	After testing or between insoluble samples run a pipette of appropriate solvent using cleaning mode.
Simple!	Precise!	Convenient!

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The solutions and viscometer were allowed to acclimate to the ambient temperature for half an hour prior to taking measurements. Four measurements were taken for each range of solutions at each temperature; however, the first measurement was not recorded. The first measurement was considered a 'prime'. This "priming" was done to reduce contamination from the prior solution used.

After carrying out experiments with three solutions (12 measurements), the instrument underwent two cleaning cycles with distilled water. The measurements were taken in order of least viscous solution to most viscous starting with the 100% distilled water solution and ending with the 10% distilled water solution. After the final set of measurements at a particular temperature, the unit underwent three cleaning cycles. The first with 70% Isopropyl alcohol, and the final two with distilled water. All data measurements were taken with the viscometer in Automatic mode.

Analysis: It has been observed that other syrups such as kokum, mango pulp, and apple syrup follow a simple Arrhenius model [1]:

$$\eta = A_0 \, e^{\frac{E_a}{RT}} \qquad \text{Eq. 1}$$

Equation 1: η: viscosity, T: absolute temperature, R: gas constant E_a and A_0: constants [1].

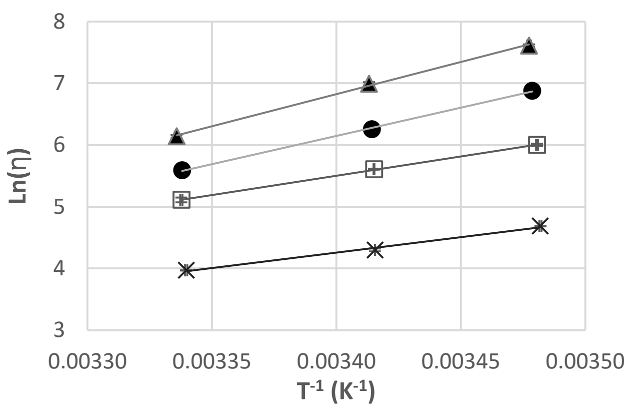

Figure 2. Select linearized plots of natural log of viscosity plotted against the inverse of the absolute temperature. Percentages v/v water/corn syrup: x: 30%, □: 20%, ●: 15%, ▲:10%.

To determine whether the data in this experiment fit this trend, the natural log of the viscosity for each temperature was plotted against the inverse of the temperature as described by a simplified linearization of the Arrhenius model:

$$\ln \eta = A + \frac{B}{T} \qquad \text{Eq. 2}$$

Equation 2: η: viscosity, T: absolute temperature, A and B: constants (Hrma 2008).

The average viscosities of each concentration were plotted against the average temperature range of the experiments seen in Figure 1. As can be seen in Figure 2, the data also follows linear trends following suit with the syrups in Swami's study.

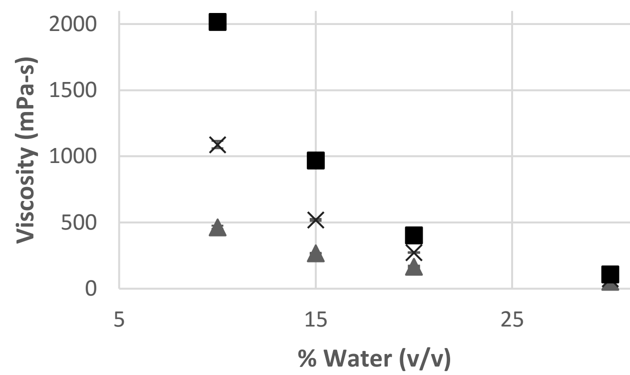

Figure 3. Viscosity plotted against solution concentration (percentages v/v water/corn syrup) in three temperature ranges. x: 19.6 + 0.06 °C, ■: 13.8 + 0.217 °C, ▲: 26.5 + 0.07 °C

As the concentration of water decreases, the viscosity of the solution increases within a temperature range as can be seen in Figure 2. This was also observed in Beckett's study with golden syrup and water across solutions of 100, 90, and 60 % golden syrup in water at 13 °C [2].

At fixed solution concentrations against different temperatures, we observe that the slope of the linearized plots increases as the concentration of water decreases seen in Table 1. This makes sense as the slope in the Arrhenius model relates to the activation energy, in this case the energy required for the liquid to flow. It makes sense that higher concentrations of corn syrup will lead to more viscous solutions and require more energy establish a flow.

Table 1. The slope (B-constant) from the linearization of the simplified Arrhenius model, statistical analysis done with regression tool in Excel 2013.

%Water	B-Const	St. Err.	P-Value
30	5011	417	0.05
20	6241	117	0.01
15	9147	276	0.02
10	10407	423	0.03

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Conclusion: The trends in the viscosity data acquired with the *micro*VISC™ across different temperatures and concentrations follow those seen in other studies [1-4]. Combined with the trends in activation energy found from data fitted to an Arrhenius model shows that the viscometer can deliver reliable temperature dependent viscosity data.

References:

1. Swami, Shrikant Baslingappa, Nayan Singh Thakor, and Seema S. Wagh. "Effect of temperature on viscosity of kokum, karonda, mango pulp and cashew apple syrup." *Agricultural Engineering International: CIGR Journal* 15.4 (2013): 281-287.
2. Beckett, F. M., et al. "An experimental study of low-Reynolds-number exchange flow of two Newtonian fluids in a vertical pipe." *Journal of Fluid Mechanics* 682 (2011): 652-670.
3. Hrma, Pavel. "Arrhenius model for high-temperature glass-viscosity with a constant pre-exponential factor." *Journal of Non-Crystalline Solids* 354.18 (2008): 1962-1968.
4. Seeton, Christopher J. "Viscosity-temperature correlation for liquids." *STLE/ASME 2006 International Joint Tribology Conference*. American Society of Mechanical Engineers, 2006.

Contact:

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