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Characterizing the non-Newtonian behavior of toothpaste

Key Words: viscosity, shear rate, toothpaste, shear thinning, power law fluid

Goal: The flow behavior of WHITE LABS toothpaste was characterized using the *micro*VISC™. The toothpaste exhibited shear thinning behavior and the viscosity was fit to a power law model. A simple analysis confirmed that the measurement shear rate range was relevant to the application of the product which involves extrusion from a tube.

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Introduction

Flow is involved in both the manufacturing and application of toothpaste since each involves pumping or squeezing through a tube. Therefore, measuring viscosity under the appropriate conditions is crucial for predicting processability and performance. Toothpaste can exhibit various types of non-Newtonian behavior depending on the specific polymer and particle additives in the formulation. In this application note, the viscosity of WHITE LABS toothpaste was measured as a function of shear rate. The sample was well characterized as a power law fluid and a simple analysis established consistency between the measurement shear rates and those typical of the application.

Experiment

Viscosity was measured with the *micro*VISC™ using a B20 chip which has a flow channel depth of 200 μm. The shear rate was varied between 5 and 50 sec^{-1} with three measurements made at each rate. Testing was performed at room temperature (21.4°C) with a total sample volume requirement of less than 400 μL.

Viscosity Data and Discussion

The viscosity data versus shear rate is presented in **Figure 1**. Since the behavior was non-Newtonian, the Weissenberg-Rabinowitsch-Mooney (WRM) correction was applied to obtain the true values. The first step is to determine the true shear rate ($\dot{\gamma}_{true}$) from the apparent value ($\dot{\gamma}_{app}$) and the shear stress (τ) with the following equation.

2420 Camino Ramon, Suite 240 San Ramon, CA 94583
P: (925) 866-3801 F: (925) 866-3804

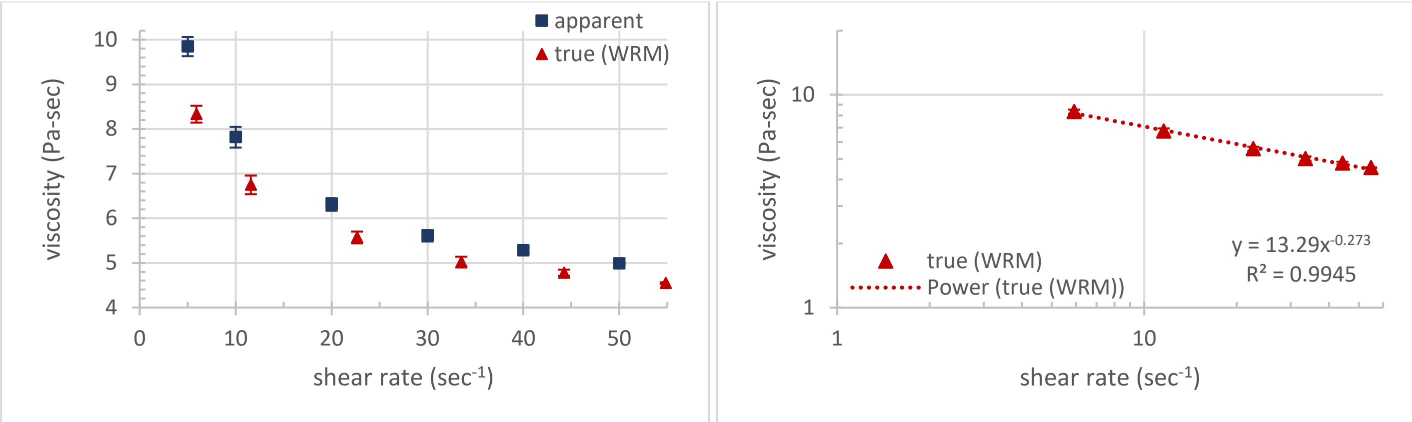

Figure 1: Viscosity versus shear rate for WHITE LABS toothpaste. Apparent viscosity is compared to the true obtained after the WRM correction (*left*). The true or corrected viscosity data is shown along with a fit to the power law model (*right*). Error bars represent one standard deviation.

$$\dot{\gamma}_{true} = \frac{\dot{\gamma}_{app}}{3}\left[2 + \frac{d\left(\ln \dot{\gamma}_{app}\right)}{d(\ln \tau)}\right]$$

The true viscosity (η_{true}) is then calculated from the shear stress and true shear rate.

$$\eta_{true} = \frac{\tau}{\dot{\gamma}_{true}}$$

Both the apparent and true viscosity values are included in **Figure 1** (*left*). Applying the correction removes any dependence on the measurement geometry such that the true viscosity is generally applicable. The data can now be related to the application process of squeezing or flowing from a circular tube.

Presenting the corrected data on a log-log scale more clearly illustrates that a power law model describes the behavior over the shear rate range tested (**Figure 1**, *right*). This model has the form $\eta = k\dot{\gamma}^{n-1}$. The power law exponent characterizing the shear thinning of the toothpaste is $n = 0.73$. The parameters associated with the flow of the toothpaste from the tube during application include the volumetric flow rate, *Q*, and the radius at the outlet, *R*. Common values for these are $Q = 1\,cm^3/sec$ and $R = 3 - 4mm$. This information is sufficient to estimate the true shear rate at the wall of the tube with the following equation.

$$\dot{\gamma}_R = -\left.\frac{du}{dr}\right|_R = \frac{(3n+1)}{n}\frac{Q}{\pi R^3}$$

This expression is derived from the radial velocity ($u = u(r)$) profile of a power law fluid. Inserting the values for *n*, *Q*, and *R* yields a shear rate range of 22 – 52 sec^{-1}. This is consistent with the range tested for the toothpaste and confirms the relevance of the measurement to the application.

Concluding Remarks

The *micro*VISC™ was used to measure the viscosity of a non-Newtonian toothpaste sample. The data was easily corrected to provide the true shear rate dependent viscosity which can then be generally applied to any flow configuration. It was confirmed that the data was collected at shear rates consistent with the application and could then be used to predict performance of the product.

If this note is helpful, please let us know! If you have questions or need more information about this product or other applications, please contact us:

Main Office — 1 925 866 3801

Sales – Sales@RheoSense.com

Information — info@RheoSense.com