

APPLICATION NOTE

Hygienic Products – Kinexus®

Quantifying Shear Thinning Behavior on a Rotational Rheometer Using the Power Law Model

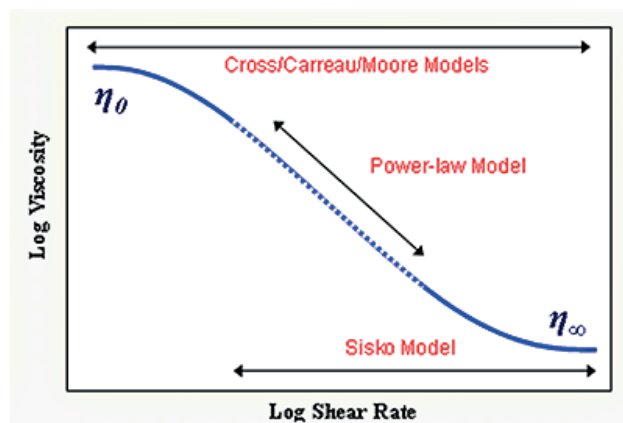
Introduction

The rheological properties of a material can influence how it is visually and texturally perceived and how it is likely to behave during processing. For example, very shear thinning materials will be highly responsive to changes in applied stress while Newtonian materials* will show much lesser dependence. Since most products of interest tend to be shear thinning materials it is important to be able to quantify such behavior. This can be done by evaluating the power law region of a flow curve as shown in Figure 1. This region appears linear on a log-log plot of viscosity vs. shear rate with a constant gradient observed but shows power law dependence when plotted on a linear scale.

Mathematically, this region of the flow curve can be described using the Power Law or Ostwald de Waele Model given in Equation 1:

$$\sigma = k\dot{\gamma}^n \text{ or } \eta = k\dot{\gamma}^{n-1}$$

k is the consistency, n is the power law index, σ is the shear stress, $\dot{\gamma}$ is the shear rate.



1 Diagram showing an ideal flow curve and the relevant models for describing its shape*

Consistency has the units of Pas^n but is numerically equal to the viscosity measured at 1s^{-1} . The power law index ranges from 0 for very shear thinning materials to 1 for Newtonian materials.

Once these parameters are known, the equation can be used to estimate the viscosity at any shear rate value within the shear thinning region; however, it is important not to use the equation outside of the measured shear rate range since a Newtonian region may exist either side of the measurement region, depending on the material under test.

Experimental

- The shear thinning behavior of a skin lotion was evaluated by performing a table of shear rate test and analyzing the resultant curve by fitting a power law model.
- Rotational rheometer measurements were made using the Kinexus rotational rheometer with a Peltier plate cartridge and a roughened parallel plate measuring system¹, and using standard pre-configured sequences in the rSpace software.
- A standard loading sequence was used to ensure that both samples were subject to a consistent and controllable loading protocol.
- All rheology measurements were performed at 25°C.
- The flow curve was generated using an equilibrium table of shear rates test between 0.1 and 100 s^{-1} and a power law model fitted to a manually selected portion of this curve.

*Newtonian fluids are named after Sir Issac Newton (1642 - 1726) who described the flow behavior of fluids with a simple linear relation between shear stress [mPa] and shear rate [$1/\text{s}$]. This relationship is now known as Newton's Law of Viscosity.

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Results and Discussion

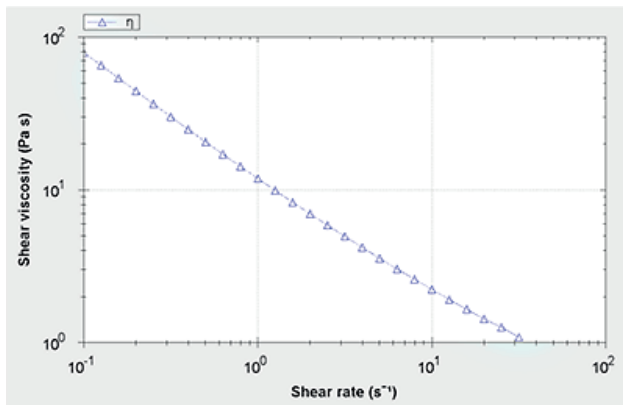
Figure 2 shows the viscosity-shear rate curve for the skin lotion. Clearly this product shows shear thinning behavior, evidenced by the rapid drop in viscosity with increasing shear rate. Although there is some slight curvature at higher shear rates, the data appears relatively straight on a double-logarithmic plot at lower shear rates.

Due to the slight curvature above approximately 10 s^{-1} , only data between between 0.1 and 10 s^{-1} has been included in the analysis since the data appears most linear in this region (when plotted logarithmically). The curves for both the model fitted and original data are shown graphically in Figure 3 and the fitting parameters and correlation coefficient are given in Table 1.

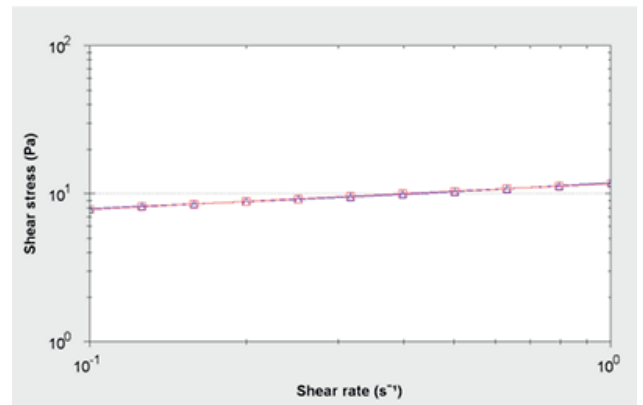
Considering that $n = 1$ for Newtonian materials and $n = 0$ for the most non-Newtonian materials, then it can be

established that this material is highly shear thinning. This shear thinning index can also be used to compare between different products for benchmarking purposes or to predict behavior in a relevant process or application, since this value is often required in many models describing the flow behavior on non-Newtonian liquids. In general, the lower the value of n the more easily it should be broken down under the application of shear. The consistency k is numerically equal to the viscosity at 1 s^{-1} and has a value of 11.71 for this particular sample. This can be useful as a general measure of viscosity for comparative purposes.

The correlation coefficient is a good measure of how well the model fits the data with a value as close to unity as possible preferable. For this particular sample, the actual value is 0.988 indicating good correlation between measured and predicted data.



2 Viscosity-shear rate data for a skin lotion

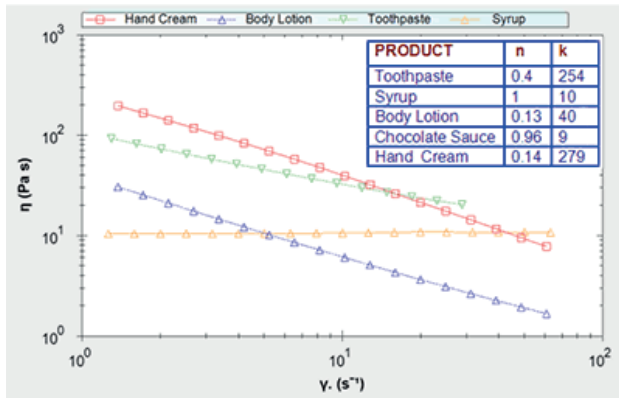


3 Original data (blue) and power law model fitted data (red) between 0.1 and 10 s^{-1}

Tab 1. Model fitting parameter data

Sample Description	Experiment Name	Action Name	k1	η	Chi square	Correlation Coefficient
Skin lotion	Analyse_0004-1	Power Law Model Fit	11.71	0.1735	617.2	0.9908

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4 Data and power law model fits for various samples

Figure 4 shows similar data for a number of other common consumer products and their corresponding fitting parameters.

Once k and n have been determined, it is possible to use these values to predict the viscosity at any shear rate using the power law equation. This may prove useful in selecting optimum packaging, reformulating a product to meet specific requirements or determining how the product will behave during manufacture or on the packing line. This model, however, should only be used to predict behavior within the region where power law behavior is observed since it does not describe the curvature that may be observed at higher or lower shear rates. To describe behavior outside of this region, the Sisko or Cross models may be more appropriate.

Conclusion

The shear thinning behavior of a skin lotion was evaluated by performing a table of shear rate test and analyzing the resultant curve using a power law model.

The Power law model was found to give a good fit to the flow curve between 0.1 and 10 s^{-1} yielding a value of 0.1735 for n and a value of 11.71 for k . This indicates that the material is highly shear thinning with a viscosity 1000 times greater than water at a shear rate of 1 s^{-1} .

Such a model has been shown to be useful for quantifying shear thinning behavior and also for comparing between products and formulations.

Please note...

Testing is recommended to be undertaken with cone and plate or parallel plate geometry – with the latter being preferred for dispersions and emulsions with large particle sizes. Such material types may also require the use of serrated or roughened geometries to avoid artefacts relating to slippage at the geometry surface.

*This Application Note be found online at AZOM
...webadresse.