Viscoelastic Property Determination – A New Application for Brookfield Viscometers

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Introduction

Over the last 25 years, vane rheometry has been extensively used for yield stress measurements of non-Newtonian materials in varied systems. Advantages of the vane method include elimination of wall-slip effects, minimum disturbance to the sample, quick single point-in situ yield stress measurements, fewer problems from particulate materials, and reduced viscous heating due to larger gap size.

Approach

Brookfield YR-I rheometers use vane spindles to measure yield stress of materials. The resistance offered by the material to vane rotation produces a torque-time profile, and the peak stress from the profile is considered the yield stress of the material.

Determination of the phase angle

An elastic material, when tested on a Brookfield YR-I, would assume the spring windup line. Any deviation from the ideal elastic line can be attributed to viscous effects present in the material. As a reasonable deduction, the area between the extended linear viscoelastic response (the initial linear region) and the ideal elastic line, A″ corresponds to the viscous effect of the material, while the area between the extended linear viscoelastic response and the Newtonian line, A′ represents the elastic effect, see Figure 1. Similar to the phase angle calculation in dynamic measurement using storage modulus (G′) and loss modulus (G″), the phase angle from Brookfield YR-I data can be calculated as,

$$\delta = \tan^{-1}\left(A''/A' \right)$$

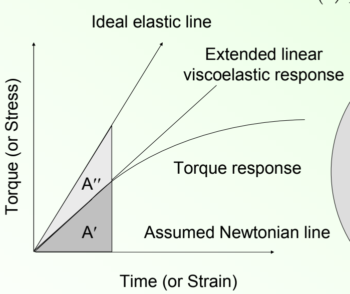


Fig. 1 Areas representing viscous and elastic effects of the material in Torque-Time Profile

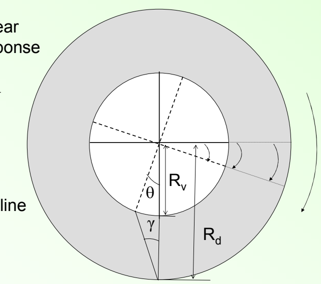


Fig. 2 Shear strain (γ) Calculation

Determination of true strain and shear modulus

Three different approaches have been considered and the stress or strain values differ for each approach

A. NCSU Approach - Deformation Zone Estimation

The calculation of true strain depends upon the extent of the deformation zone. The effect of vane rotation is observed not only in the material trapped within the blades of the vane but also extends to a finite distance from the vane edge into the material called the deformation zone. After an angular rotation of the vane (θ), a strain value of γ is observed in the material, see Figure 2. If the radius of the vane and the radius of the deformation zone are R_v and R_d, the strain can be approximated according to the following equation for small angles,

$$\gamma = \tan^{-1}\left[\frac{\tan\theta}{(R_d/R_v) - 1} \right]$$

Shear modulus (G) is computed as the ratio of the shear stress (σ) value to the shear strain (γ) value, i.e.,

$$G = \frac{\sigma}{\gamma}$$

B. Alderman Approach

Alderman et al. (1991) calculated a distinct stress value for shear modulus computations and accordingly the shear modulus as,

$$G = \frac{M}{4\pi H\theta}\left(\frac{1}{R_v^2} - \frac{1}{R_c^2} \right)$$

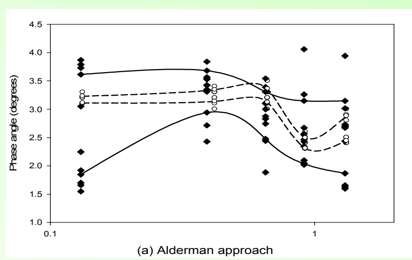
C. Brookfield Approach

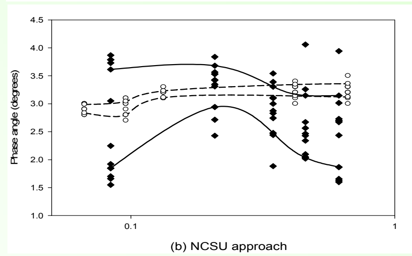
The approach considers the rotation of the vane (θ) equivalent to the true strain (γ) observed in the material, i.e.,

$$G = \sigma/\theta$$

Materials and Methods

Various concentrations of polyacrylamide and gelatin gels were the model systems to represent perfectly elastic and different viscoelastic materials respectively. A controlled stress rheometer, Rheologica StressTech was chosen as the control machine. Serrated bob and cup was the attachment used with StressTech, while 5 cups of sizes 10%, 30%, 50%, 70% and 90% greater than the vane diameter were used with vane spindle V-72 as attachments for the Brookfield YR-I. The cups determine deformation zones for the NCSU Approach. Stress sweeps were conducted to determine the linear viscoelastic region, and strain control experiments were conducted on the StressTech. The Brookfield YR-I was run at various rotational speeds.





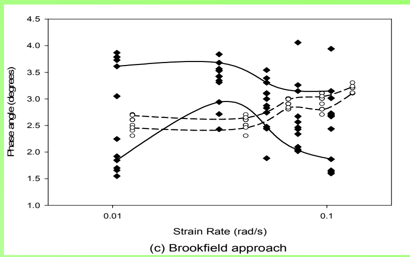


Fig 3. 4% Gelatin phase angle data for the three approaches for cup 1; ○ StressTech data; ◆ Brookfield data; ―○― StressTech confidence limits; ―◆― Brookfield confidence limits.

Results

Preliminary results suggest cup 1 yields results most comparable to the StressTech results, see Table 1. Statistical analysis suggest Alderman approach as the best for shear modulus computation, see Figure 3. Therefore, a protocol was developed for the use of Brookfield YR-I as a viscoelastic rheometer.

1. Cup 1 should be used with Brookfield YR-I
2. Brookfield YR-I HB series should be used with materials having a yield stress greater than 30 Pa while Brookfield YR-I RV series should be used with materials having a yield stress below 30 Pa
3. Rotational speeds below 1.0 rpm should be used
4. The initial 10% values from the torque-time profile should be deleted
5. Alderman approach should be implemented for shear modulus calculation

Table 1. Preliminary results from Polyacrylamide and gelatin gels

Cup Size	Alderman		NCSU Approach		Brookfield	
Parameter	Phase Angle	Shear Modulus	Phase Angle	Shear Modulus	Phase Angle	Shear Modulus
Cup 1	√	√	√	√	√	X
Cup 2	X	√	X	X	X	X
Cup 3	X	√	X	X	X	X
Cup 4	X	√	X	X	X	X
Cup 5	X	√	X	X	X	X

Note: A tick (√) denotes agreement between StressTech data and Brookfield YR-I while a cross (X) denotes a disagreement

Conclusion

The Brookfield YR-I – cup 1 combination along with the Alderman approach for determination of shear modulus and rate, and the NCSU approach for phase angle estimation, produces viscoelastic properties of materials.

Acknowledgments

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