Use of a Brookfield YR-1 Rheometer for Characterization of Viscoelastic Properties

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Abstract

The Brookfield YR-1 Rheometer is an affordable instrument that uses vane technology to determine the yield stress of viscoelastic materials. The Brookfield torque response is based on the degree of a spring wind-up, therefore deviations from an ideal elastic response may be attributed to viscous dissipation. The ratio of energy dissipated to the energy stored by the Brookfield spring can be used to calculate a phase angle and other viscoelastic properties for the material. Such viscoelastic properties are currently determined by significantly more expensive instrumentation. The objective of this research was to determine if viscoelastic characterization of food materials could be obtained through analysis of torque response data collected from a Brookfield YR-1 Rheometer. A StressTech controlled stress rheometer was used over a frequency range of 0.001-0.01 Hz to characterize the viscoelastic properties of ketchup and mayonnaise at room temperature. A Brookfield YR-1 Rheometer was used to collect data for the same materials over a similar frequency range. By considering the energy stored and lost through the spring, a phase angle was determined. This information, coupled with the complex modulus determined from the linear region of the failure curve, was used to compute the storage and loss moduli. When compared with results obtained from a controlled stress rheometer, the Brookfield YR-1 generated similar viscoelastic properties (R^2>0.95), specifically phase angle, storage and loss moduli. These results suggest that the Brookfield YR-1 Rheometer can be used for reliable collection of fundamental viscoelastic data of food materials, introducing a novel protocol for characterizing these important food properties.

Objective

Determine if viscoelastic characterization of food materials could be obtained through analysis of torque response data collected from a Brookfield YR-1 Rheometer.

Data Collection

Viscoelastic Materials

-Ketchup

-Mayonnaise

StressTech Controlled Stress Rheometer

-Equipped with a 25 mm serrated Mooney-Couette bob and cup.

-Oscillatory measurements performed at constant stress of 25 Pa between 0.001-0.01 Hz at 25°C.

-Measured phase angle (δ), complex (G*), storage (G'), and loss (G'') moduli.

Brookfield YR-1 Rheometer

-Equipped with a #72 vane spindle.

-Torque response measurements performed between 0.1-1.0 rpm (0.0017-0.017 Hz) at 25°C.

-Measured displacement of each material by vane through deflection of calibrated spiral spring.

Data Analysis

Determination of Phase Angle (δ)

-The ratio of energy dissipated to energy stored was calculated and used to determine δ (Equation 1).

-Dissipated (A'') and stored (A') energies were determined by calculating areas underneath the torque response curve generated by the material and the spring (Figure 1).

-Areas were determined by fitting a third degree polynomial trend line ($R^2 \geq 0.95$) to the viscoelastic material and a linear trend line (R^2 =1) to the spring, then integrating the resulting equations from 0 s to the time (s) at peak torque response.

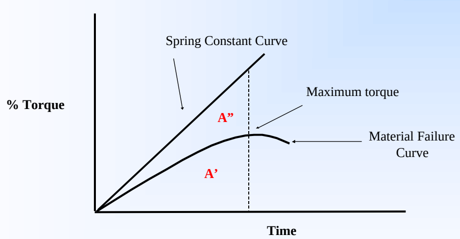

Figure 1. Determination of stored (A') and dissipated (A'') energy of a viscoelastic material.

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

Data Analysis (continued)

Determination of Complex (G*), Storage (G'), and Loss (G'') Moduli

-% Torque and Time (s) values were converted to Stress, σ, (Pa) and Apparent strain, γ_A, values, respectively (Equations 2 and 3).

-G* was determined as the slope from the linear region of the failure curve (Figure 2).

-G' and G'' were subsequently calculated using Equations 4 and 5.

Equation 2 $\sigma_o = M_o(2/\pi d^3)(h/d + 1/6)^{-1}$

where,

M_o= peak torque (Nm)

d= vane diameter (m)

h= vane height (m)

Equation 3 $\gamma_A = \theta/(d_f/d-1)$

where,

$\theta = (\Omega t) - (\%M * C_s)$

Ω= rotational speed (rad/s)

d = vane diameter (m)

d_f= fracture diameter of material (m)

C_s=0.01164 (rotation of vane (rad) / % torque)

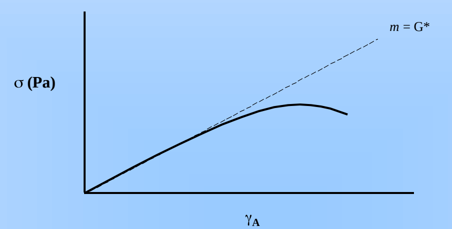

Figure 2. Determination of G*.

Equation 4 G' = G*cos _

Equation 5 G" = G*sin _

Results

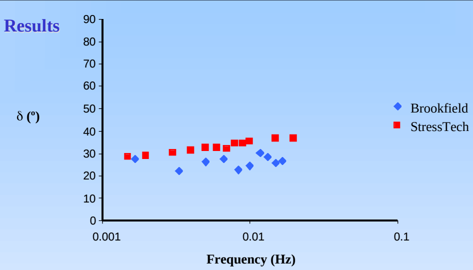

Figure 3. Phase angle (δ) data for ketchup.

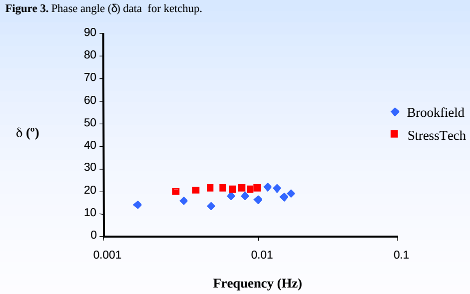

Figure 4. Phase angle (δ) data for mayonnaise.

Results (continued)

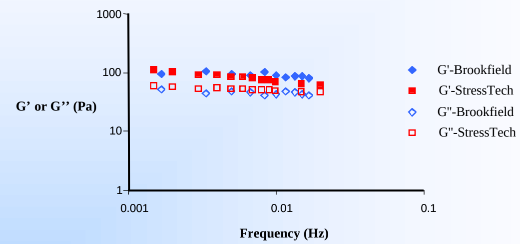

Figure 5. Storage (G') and loss (G'') moduli for ketchup.

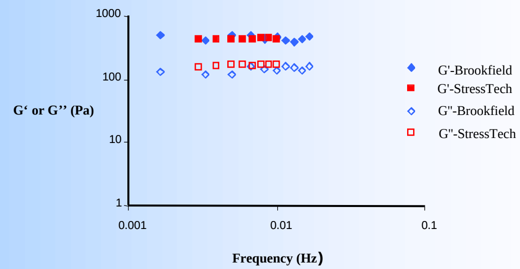

Figure 6. Storage (G') and loss (G'') moduli for mayonnaise.

Conclusions

-When compared with results obtained from a controlled stress rheometer, the Brookfield YR-1 rheometer generated similar viscoelastic properties, including phase angle (δ), complex (G*), storage (G'), and loss (G'') moduli.

-Results suggest that the Brookfield YR-1 rheometer can be used for reliable collection of fundamental viscoelastic data of food materials, introducing a novel protocol for characterizing these important food properties.

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