A Vane-in-Cup Approach to Measure Viscoelastic Properties of Gelatin Gels through Torque-Time Responses from Brookfield YR-I Viscometer

Deepti Tanjore, Christopher R. Daubert*

Department of Food Science, Bioprocessing, and Nutrition Science, North Carolina State University, Raleigh, NC 27695-7624, USA

*Corresponding author: chris_daubert@ncsu.edu
Fax: x1.919.515.7124

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Abstract:
Viscoelastic properties are traditionally measured using sophisticated instrumentation, and the high cost of these rheometers may limit utility. This research attempts to enable viscometers that can provide a torque-time response, with vane attachment and a recommended cup size, to measure viscoelastic properties. Phase angles and shear moduli of model systems (gelatin and polyacrylamide gels) were calculated using torque-time response and deformation zone concept. The methods were applied to data obtained from Brookfield YR-I viscometer and the calculated values were compared with the data obtained from oscillatory testing on a stress controlled rheometer. The methods were improved in several areas by testing different cup sizes, rotational speeds, and viscometers and correcting torque-time responses to obtain most accurate results possible. The developed method, along with the torque-time response obtained from the viscometer, was capable of measuring viscoelastic parameters for the tested materials and further development could design a new quality control device directed towards viscoelastic property measurement.

Zusammenfassung:
Viskoelastische Eigenschaften werden traditionell unter Verwendung anspruchsvoller Instrumente gemessen, wobei die hohen Kosten dieser Rheometer den Einsatzbereich begrenzen. In dieser Arbeit wird versucht, Viskosimeter mit einer Drehmoment-Zeit-Antwort mit Schaufel und empfohlener Cup-Größe zu verwenden, um viskoelastische Eigenschaften zu messen. Phasenwinkel und Schubmodule von Modellsystemen (Gelatine und Polyacrylamidgelen) werden aus dem Drehmoment-Zeit-Ansprechverhalten und dem Deformationszonen-Konzept berechnet. Die Methoden wurden anhand von Daten eines Brookfield YR-I-Viskosimeters getestet und die berechneten Werte wurden mit den Daten aus oszillatorischen Tests mittels eines Stress-Rheometers verglichen. Die Methoden wurden kontinuierlich in mehreren Bereichen durch das Testen verschiedener Cup-Größen, Drehzahlen und Viskosimeter und Korrektur von Drehmoment-Zeit-Antworten verbessert, um möglichst genaue Ergebnisse zu erhalten. Die entwickelte Methode, in Kombination mit der Drehmoment-Zeit-Antwort des Viskosimeters, wurde für die Messung von viskoelastischen Parametern der getesteten Materialien verwendet, und eine weitere Entwicklung kann zu einer neuen Einrichtung zur Qualitätskontrolle zur Bestimmung der viskoelastischen Eigenschaften führen.

Résumé:
Les propriétés viscoélastiques sont traditionnellement mesurées à l'aide d'instruments sophistiqués, et le coût élevé de ces rhéomètres peut limiter leur utilisation. Cette recherche tente de permettre aux viscosimètres qui peuvent fournir une réponse couple-temps, avec l'attachement à palettes et une taille de cylindre recommandé, de mesurer les propriétés viscoélastiques. Les angles de phase et les modules de cisaillement des systèmes modèles (la gélatine et des gels de polyacrylamide) ont été calculés en utilisant la réponse temporelle du couple et le concept de zone de déformation. Les méthodes ont été appliquées aux données obtenues à partir du viscosimètre Brookfield YR-I et les valeurs calculées ont été comparées avec les données obtenues lors des essais oscillatoires sur un rhéomètre à contrainte contrôlée. Les méthodes ont été améliorées dans plusieurs domaines en testant différentes tailles de cylindre, différentes vitesses de rotation, et différents viscosimètres et en corrigeant la réponse temporelle du couple afin d'obtenir des résultats les plus précis possible. La méthode développée, avec la réponse temporelle du couple obtenue à partir du viscosimètre, a été capable de mesurer des paramètres viscoélastiques pour les matériaux testés et un futur développement pourrait permettre de concevoir un dispositif pour le contrôle de qualité mesurant les propriétés viscoélastiques.

Key words: viscoelasticity, vane, shear modulus, phase angle, deformation zone

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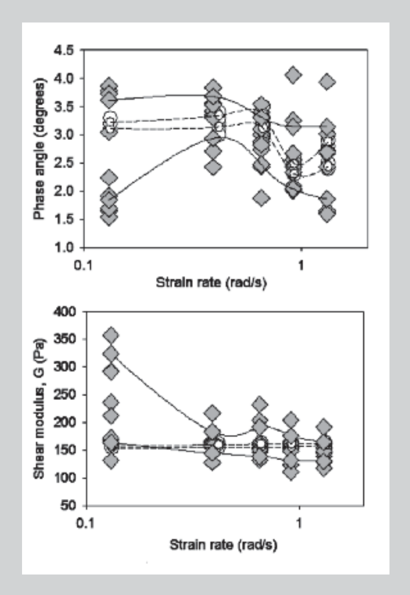

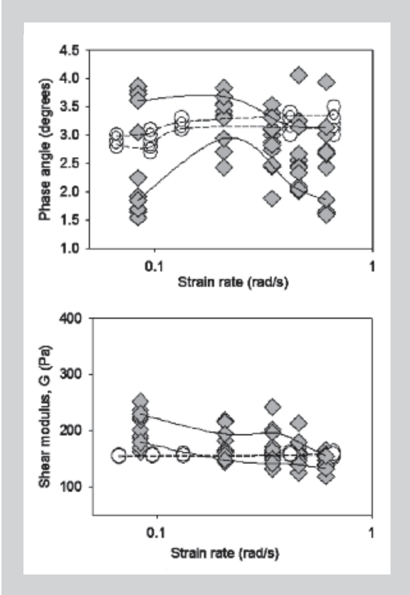

Figure 10 (left): Phase angles and shear moduli of 4 % gelatin gels associated with strain rate for the Alderman method data with cup 1 (○: control data, ◆: Alderman method data; - ○ -: control confidence limits, - ◆ -:Alderman data confidence limits).

Figure 11: Phase angles and shear moduli of 4% gelatin gels associated with strain rate for the deformation zone method with cup 1 (○: control data, ◆: deformation zone data; - ○ -: control confidence limits, - ◆ -: deformation zone data confidence limits).

batch of 4 % gelatin with both the methods. Confidence intervals at a 95 % confidence level were developed for the calculated data from Cup 1 and compared with control. An overlap of the areas covering the confidence intervals signified similarity between the data produced by both instruments. The Alderman and deformation zone methods provided similar phase angle and shear moduli data for cup 1. If deformation zone method was applied on results from infinite cup, not only were the phase angles significantly different from control data (Figure 7) but same strain rate values corresponding to each rotational speed cannot be attained. This is because strain rates were calculated based on strain, which in turn is based on the % *M* observed in the material each time (Equation 5). Every test on the viscometer for the same material at the same rate exhibits variability in %M due to variability from the measurement capabilities of the instrument. Accordingly, replication of data at the same strain rate was not possible, though similar strain rate values can be achieved. On the other hand, better estimations of shear moduli and feasibility of repeating experiments at the exact same strain rates were observed with the Alderman method for cups of larger sizes too (Figures 7, 9b, and 9c). Due to consistency in shear moduli results regardless of cup size the Alderman method seems more apt for shear moduli calculation for the model systems. However, the calculations with Alderman method were not extended to commercial products or other gels, limiting our deductions about using this approach to calculate shear moduli to a wide range of materials. To measure viscoelastic properties of gelatin gels, phase angle calculation presented in Section 2.1. and shear modulus calculations using Alderman method presented in Section 2.2.2. should be used in Equations 14 and 15.

5 CONCLUSION

This study is oriented towards incorporating data obtained from an inexpensive instrument into a proposed theory and obtaining rheological properties that can only be obtained from an expensive instrument. Though the goal was not completely achieved, the results obtained through the study are of considerable importance to future work in this area. The proof of theory is buttressed by experiments from combinations of a single equipment (Brookfield YR viscometers) and some materials (gelatin gel, polyacrylamide gel, and commercial food products). The results provide us the appropriate test conditions required for measurement of viscoelastic properties using a vane-in-cup approach for the tested combinations. Cup 1 (radius of cup 10 % beyond the vane radius) was found to be best geometry to apply the deformation zone concept on the torque-time responses at low rotational speeds (below 1.0 rpm). The strength of the materials dictated the choice of test viscometer. A statistical analysis confirmed the Alderman technique as an appropriate selection for shear moduli and rate calculations for model test systems, while the proposed methods in this work proved suitable for phase angle determination along with the Cup 1. The phase angle measurement method deduced agreeable results with commercial food products as well. Thus, this study forwards the idea that simple viscoelastic parameters of materials can be obtained from the torque-time response with a vane-in-cup attachment and adopting the proposed experimental protocol. Further research is required, not only in improving the methods of testing for the present viscometer and attachment, but also expanding the study to more viscometers and materials. Such studies can potentially develop an inexpensive and easy-to-handle instrument with accurate viscoelastic property determination capabilities.

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