Vane Sensor System in Small Strain Oscillatroy Testing

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Abstract:
To overcome difficulties (slip, sample disturbance) associated with traditional sensors, a semi-empirical method was developed to allow the use of a 4-bladed vane sensor in small strain oscillatory testing. It was assumed that the vane sensor acted as a bob with an acting radius, R_V, different from the actual radius of the vane (0.02005 m). To solve for R_V, the complex modulus obtained using a concentric cylinder sensor from reference viscoelastic fluid, was set equal to the complex modulus equation for vane sensor. R_V values were grouped into three phase shift ranges from 5° to less than 16°, from 16° to less than 60°, and from 60° to 90° and they were 0.01883, 0.01869, and 0.01850 m, respectively. These values were used in the calculation of viscoelastic properties of eight commercial food products, which resulted in complex modulus values within 15% of those obtained using a concentric cylinder sensor. Results showed that this particular vane and cup system can be used to directly measure the storage and loss moduli of viscoelastic material and phase shift within the upper frequency value of 6.28 rad/s. Above 6.28 rad/s, there is an inconsistency in phase shift angles measured using vane method. This method is ideal for testing thixotropic food systems because disturbance is minimal during sample loading, giving more accurate viscoelastic measurements.

Zusammenfassung:
Um einige messtechniche Probleme (Wandgleiten, Probenzerstörung) üblicher Geometrien zu beheben, wurde eine halbempirische Methode entwickelt, die es erlaubt einen 4-blättrigen Flügelgeometrie für oszillatorische Messungen bei kleiner Amplitude zu verwenden. Als Arbeitshypothese gilt, dass die Flügelgeometrie wie der Innenzylinder einer Couette-Geometrie mit einem effektiven Radius R_V wirkt und dass dieser Raduis aber vom wirklichen Radius der Flügel (0.02005 m) abweicht. Um R_V zu bestimmen, wurde der komplexe Modul, welcher aus einer Messung eines viskoelastischen Referenzfluids mit konzentrischen Zylindern bestimmt wurde, mit der Gleichung des komplexen Moduls für den Flügelgeometrie gleichgesetzt. Die Werte für R_V wurden in Gruppen verschiedener Phasenwinkelbereiche eingeteilt, von 5° bis unter 16°, von 16° bis unter 60°, und von 60° bis 90°; die Werte betrugen 0.01883, 0.01869, und 0.0185 m. Diese Werte wurden zur Bestimmung der viskoelastischen Eigenschaften von acht kommerzielle erhältlichen Lebensmittelprodukte verwendet. Die so ermittelten Werte für den komplexen Modulus stimmen bis auf 15% mit den Messungen in konzentrischen Zylindern überein. Die Ergebnisse zeigten, dass diese spezielle Flügelgeometrie verwendet werden kann, um direkt den Speicher- und Verlustmodul von viskoelastischen Materialien sowie die Phasenverschiebung bis zu einer Frequenz von 6.28 rad/s zu bestimmen. Oberhalb von 6.28 rad/s weichen die Phaseverschiebungen der verschiedenen Messmethoden zu stark ab. Diese Methode ist vorallem ideal zur Untersuchung von thixotropen Lebensmittelsystemen, weil die Probenzerstörung bei der Befüllung minimal ist und somit recht genau viskoelastischen Eigenschaften bestimmt werden können.

Resumée:
Afin de surpasser les difficultés (glissement, distortions non voulues de l'échantillon) associées à l'emploi de géometries traditionnelles, une méthode semi-empirique a été developée afin de permettre l'utilisation d'une géometrie de type "vane à 4 lames", pour des tests en régime de petites déformations oscillatoires. Il a été supposé que la géometrie "4 lames" agissait comme un cylindre possédant un rayon effectif, RV, différent du rayon réel des "4 lames" (0.02005 m). Afin de déterminer RV, le module complexe de fluides viscoélastiques de référence, obtenu avec une géometrie de cylindres concentriques, a été égalisé à l'équation donnant le module complexe pour la géometrie "vane". Les valeurs de RV ont été estimées à 0.01883, 0.01869 et 0.01850 m, pour des gammes de déphasage allant de 5° à moins de 16°, de 16° à moins de 60°, et de 60° à 90°, respectivement. Ces valeurs ont été utilisées pour le calcul des propriétés viscoélastiques de huit produits alimentaires commerciaux. Les valeurs des modules complexes ainsi obtenues sont identiques à 15% près aux valeurs des modules complexes obtenus en utilisant une géometrie de cylindres concentriques. Les résultats ont montré que cette géometrie particulière de "vane à 4 lames" peut être utilisée pour mesurer directement les modules de rigidité et de perte de matériaux viscoélastiques, ainsi que le déphasage, jusqu'à la fréquence limite de 6.28 rad/s. Au delà de cette fréquence, il y a une inconsistance dans les angles de déphasage mesurés avec la géometrie "vane" et la méthode associée. Cette méthode est idéale pour tester des échantillons alimentaires thixotropiques, puisque la distortion de l'échantillon associée à l'insertion de ce dernier dans la géometrie "vane", est minimale, et par consequent, les mesures viscoélastiques ainsi obtenues sont plus précises.

Key Words: Vane, rheology, oscillatory

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Theoretically, the closer the ratio of radii (R_c/R_V) to unity, the smaller the effect of non-linearity would be on the rheological measurement [15]. Due to the relationship between the cup radius and non-linearity, it is recommended that when using a slightly different size of cup other than the standard Z40-DIN cup, the method development described in this work, testing reference fluid to obtain the R_V values, should be repeated.

The method of using a vane sensor in small strain oscillatory testing offers exciting advancements to evaluating viscoelastic properties of 'problematic' food systems. As an example, it would be extremely useful in measuring viscoelastic properties of food materials possessing a weak gel structure, because the structure is easily destroyed by the sample loading process when using the traditional sensors. Another application would be in measuring the viscoelastic properties of the final product of slow gelling systems, such as in yogurt. Normally, processing yogurt would tie up the instrument for a whole day when using traditional concentric cylinder sensor because yogurt can take 4 - 6 hours to develop its final gel structure. Using disposable cups, vane sensor, and the method presented in this work (after finding the associated acting radius), measurements could be done in relatively shorter period of time by preparing the sample in the disposable cup in advance.

4 CONCLUSION

A semi-empirical method has been developed that allows the use of a vane sensor in small strain oscillatory testing. For most food samples, these moduli were within 15% from those obtained using traditional sensor such as concentric cylinder. The vane method presented in this research was limited to the upper frequency value of 6.28 rad/s. Greater error was also introduced when tests were done using a sample container having a slightly larger diameter, suggesting that the standard R_V values determined apply only for the specific vane sensor and cup (Z40 DIN) used in this research. It is necessary to repeat the method development procedure using reference fluids when using vane to measure viscoelastic properties in a geometrically different system.

Overall, research showed that the vane sensor and methodology presented is an adequate tool to directly measure the viscoelastic properties of 'problematic' foods within defined parameters.

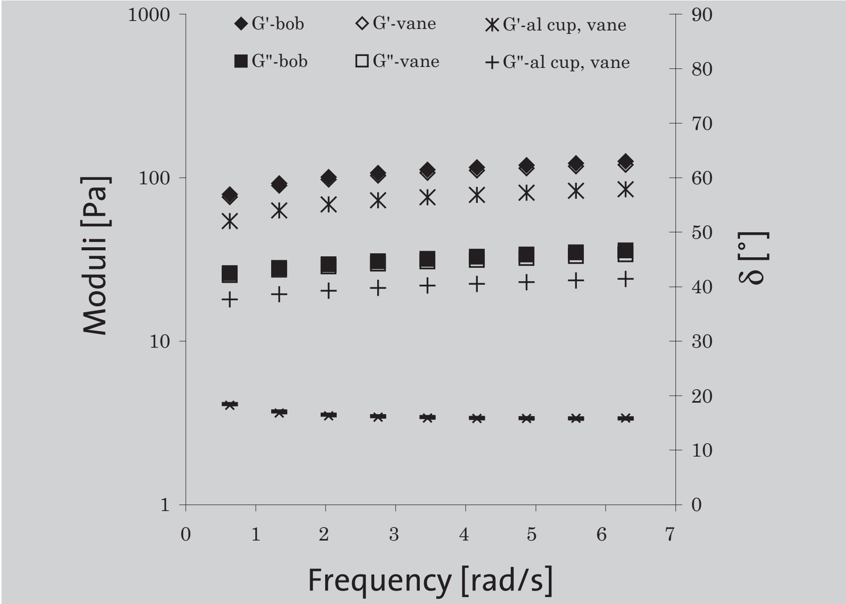

Figure 5: Moduli comparison obtained using the concentric cylinder and vane sensors in two different container sizes, disposable aluminum cup (R_C = 0.0234 m) and standard Z40 DIN cup (R_C = 0.0217 m), for Ranch salad dressing at 22 °C.

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