Apparent Viscosity and First Normal Stress of Starch Dispersions: Role of Continuous and Dispersed Phases, and Prediction with the Goddard-Miller Model

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Abstract:
Apparent viscosity, η_a, and first normal stress coefficient, ψ_1, of six different concentrations of cross-linked waxy maize (CWM), 3.5-5 % w/w, and tapioca, 2.8-4 % w/w, starch dispersions (SDs) showed power law relationships with shear rate, $\dot{\gamma}$, and increased with starch concentration. In both η_a and ψ_1, volume fraction of the granules, ϕ, played a more important role than the amylose content of the continuous phase. Slope of η_a - $\dot{\gamma}$ curves increased mildly with starch concentration, while slope of ψ_1 - $\dot{\gamma}$ curves was almost the same for CWM at all concentrations and 4 % tapioca SDs. Values of η_a and ψ_1 predicted from dynamic rheological and apparent viscosity data based on the Goddard-Miller model were in reasonable agreement with experimental values.

Zusammenfassung:
Die scheinbare Viskosität, η_a, and der erste Normalspannungskoeffizient, ψ_1, von sechs Stärkedispersionen (SDs) verschiedener Konzentration von 3.5-5% w/w vernetztem wachsartigem Mais (CWM), und 2.8-4% w/w Maniok zeigten ein Potenzgesetzverhalten in Abhängigkeit von der Scherrate, $\dot{\gamma}$, und einen Anstieg in Abhängigkeit der Stärkekonzentration. Sowohl η_a als auch ψ_1 wurde vom Volumenanteil der Körner, ϕ, stärker beeinflusst als vom Amyloseanteil der kontinuierlichen Phase. Die Steigung der η_a - $\dot{\gamma}$ Kurven vergrösserte sich ein wenig mit der Stärkekonzentration, während die Steigung der ψ_1 - $\dot{\gamma}$ Kurven fast identisch war für CWM bei allen Konzentrationen und 4% Maniok SDs. Die Werte von η_a und ψ_1 welche aus dynamischen rheologischen Daten und scheinbaren Viskositätswerten basierend auf dem Goddard-Miller Model vorhergesagt wurden, waren in guter Übereinstimmung mit den experimentellen Werten.

Résumé:
La viscosité apparente, η_a, et le premier coefficient de contrainte normale, ψ_1, de dispersions d'amidon avec six concentrations différentes de cire de maïs réticulée (CWM), 3.5-5%w/w, et de tapioca, 2.8-4%w/w, montrent des relations de loi de puissance avec la vitesse de cisaillement, $\dot{\gamma}$, et augmentent avec la concentration en amidon. Pour η_a et ψ_1, la fraction volumique des granules, ϕ, joue un plus grand rôle que la teneur en amylose dans la phase continue. La pente des η_a - $\dot{\gamma}$ courbes augmente légèrement avec la concentration en amidon, tandis que la pente des ψ_1 - $\dot{\gamma}$ courbes est presque la même pour la CWM à toutes les concentrations et 4%w/w de tapioca SD. Les valeurs de η_a et ψ_1 prédites à partir des données de la rhéologie dynamique et de la viscosité apparente, basées sur le modèle de Goddard-Miller sont en raisonnable accord avec les valeurs expérimentales.

Key words: starch dispersions, apparent viscosity, first normal stress, granules, amylose

1 *INTRODUCTION*

Starch is widely used in the food industry as a thickening agent. It is mainly composed of two polymers: amylose and amylopectin, which exist together in the form of granules. Starch granules hydrate only slightly in cold water but when the starch-water mixture is heated above the gelatinization temperature, the granules absorb large amounts of water, swelling to several times their initial size and leaching out some amylose into the solution. Upon cooling the starch dispersion (SD) forms a strong or weak gel, depending on the type of starch and its concentration.

Gelatinized SDs can be considered to be composites of swollen granules embedded in a continuous amylose network. The complex rheological behavior of a SD depends on the characteristics of the continuous and the dispersed phases, as well as the interactions between them [1 - 5]. Viscosity of SDs is strongly influenced by swelling of starch granules, which in turn

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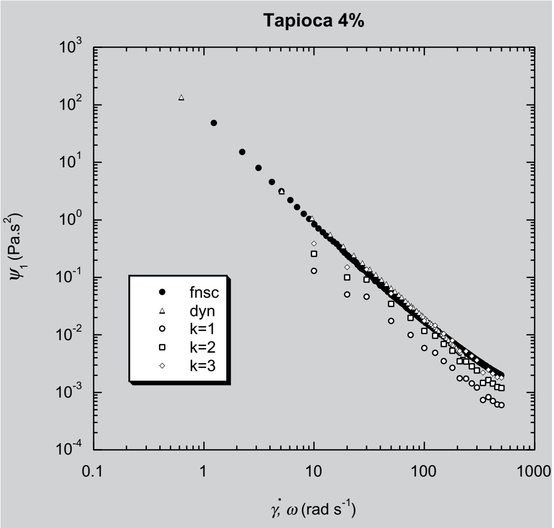

Figure 6: First normal stress coefficient from flow test down curve (fnsc), first normal stress coefficient predicted with Eq. 4 (dyn), and first normal stress coefficient predicted with Eq. 5 using different values of the empirical factor K (K = 1, K = 2, K = 3) for tapioca at 4 % w/w.

4 CONCLUSIONS

Viscosity was strongly influenced by the volume fraction of the granules, while the continuous phase played a secondary role. At the same volume fraction of granules, the viscosity of the SD increased with the rigidity of the starch granule. Decrease in apparent viscosity with shear rate was more pronounced when granules were more close - packed, probably due to increase in the number of particle-particle interactions. Experimental values of apparent viscosity were between those of complex viscosity and apparent viscosity predicted from dynamic rheological data using Eq. 2.

Normal stresses were detected in CWM (3.5 - 5 % w/w) and tapioca (3.5 - 4 % w/w): an increase with concentration is observed. Double logarithmic plots showed a linear decrease of first normal stress coefficient with shear rate with almost the same slope for all the SDs except 3.5 % and 3.8 % tapioca. Amylose content in the continuous phase moderately increased the first normal stress coefficient but results indicated that the dispersed phase is more important. Experimental values of first normal stress coefficient were between those predicted from dynamic rheological data (Eq. 4), and from apparent viscosity - shear rate data (Eq. 5) but were also dependent on the empirical factor *K*.

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