FOOD RHEOLOGY AND TEXTURE

Rao, M.A.
Department of Food Science and Technology, Cornell University, Geneva, NY, USA

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Contents

Summary

Rheology is the study of the deformation and flow of all matter. Fluid foods that contain relatively small molecules exhibit Newtonian behavior, while those containing dissolved polymers, insoluble solids, or immiscible fluids exhibit non-Newtonian flow behavior. The power law model has been used extensively to characterize non-Newtonian fluid foods. Links between viscosity, and structure and sensory stimuli, as well as in handling operations, have been established. Small amplitude oscillatory tests are being used to study the characteristics of food gels, sol-gel, and gel-sol transition. Texture represents a group of mechanical or rheological properties. Texture tests based on puncture, compression, elongation, and extrusion are being used.

1. Introduction

By definition, rheology is the deformation and flow of matter. Rheological studies on liquid and solid foods are conducted using test geometries that are amenable to mathematical analysis of the applied strain and strain rate, and the resulting linear or nonlinear stress. Results obtained from many rheological studies on fluid and solid foods have been interpreted in terms of either the characteristics of the molecules of biopolymer dispersions or the microstructure or composition of multi-component foods. In many instances, as in the viscosity of food suspensions and viscoelastic properties of gels, and the effect of temperature on the viscosity of fluid foods, the results of pioneering studies by distinguished scientists, such as Acrivos, Arrhenius, Flory, de Gennes, and Krieger are applicable (see *Newtonian and Non-Newtonian Flow, Viscoelasticity*).

There are numerous definitions for food texture, many of which are commodity-oriented and others that are feel-oriented, but it is generally recognized that texture represents a group of physical properties that are often mechanical or rheological. Texture profile analysis (TPA) has emerged as one manner of understanding the results obtained from texture tests, and several characteristics of foods have been introduced. For example, rigidity, which comes very close to being the classical elastic modulus, is one such parameter (see *Solid Foods*, *Texture in Solid and Semi-Solid Foods*).

The various topics in Food Rheology and Texture that follow cover several important subjects which are useful in better understanding the role of composition and structure on rheological behavior; also included are up-to-date measurement techniques. Because many fluid foods exhibit either Newtonian or non-Newtonian behavior, one of the articles is on Newtonian and non-Newtonian flow. The non-Newtonian behavior is due to either dissolved polymers (guar gum, xanthan gum, pectins, amylose, proteins) and/or due to the dispersed nature of the food where the dispersed phase may be made up of insoluble solids (as in suspensions) or an immiscible fluid (as in emulsions). Due to their unique nature, the rheological behavior of emulsions and suspensions are best studied separately.

In food rheology, many widely applicable models have been developed to fit shear rate ($\dot{\gamma},\ s^{-1}$) versus shear stress (σ, Pa), and to describe the effect of temperature on the rheological data of fluid foods. For example, the applicability of the power law model (Equation 1) to many fluid foods over ranges of shear rates (10-150 s^{-1}), useful in many practical applications, and that of the Arrhenius equation for quantitatively describing the effect of temperature on the viscosity (Equation 2), or the consistency index of the power law model (Equation 3), have been well documented.

$$\sigma = K\dot{\gamma}^n \tag{1}$$

$$\eta = \eta_\infty \ \exp\left(E_a / RT\right) \tag{2}$$

$$K = K_\infty \ \exp\ (E_a / RT) \tag{3}$$

Compilations of values of the power law parameters and the Arrhenius activation energies can be found in several of the references listed in the Bibliography. A number of other useful flow models (e.g., the Casson model used for characterizing chocolate) and functional models (e.g., Krieger-Dougherty model for the influence of suspended solids and the Williams-Landel-Ferry model for the effect of temperature) are available for obtaining information on fluid foods and correlating their rheological behavior, and they have been reviewed elsewhere.

Many food polymers occur naturally in plants and animals, and a few are also obtained by fermentation (e.g., xanthan gum). Most, if not all, are soluble in water and are called food gums or food hydrocolloids. Food hydrocolloids play many important roles, such as imparting desirable viscosity, yield stress, and ice crystal formation. The relationship between the viscosity and the molecular size of several carbohydrate polymers has been studied. Specifically, the viscosity $\eta_{sp} = \left(\dfrac{\eta_0 - \eta_s}{\eta_s}\right)$, based on the constant viscosity at low shear rates of the dispersions of several carbohydrate polymers, called the zero-shear or Newtonian viscosity (η_0), was related to the product of concentration (c) and intrinsic viscosity, called the coil-overlap parameter ($c[\eta]$); η_s is the viscosity of the solvent (water). The coil-overlap parameter reflects the degree of occupancy of space by the food polymer coils. Separate correlations were found for the dilute region ($c[\eta]$ up to about 4) with a slope of 1.4 and for the concentrated region with a slope of 3.3 (Figure 1). Because the intrinsic viscosity of a biopolymer is closely associated with its molecular weight (M) via the Mark-Houwink equation (Equation 4), the link between viscosity and molecular weight should be recognized.

$$[\eta] = K_{MH} \left(M \right)^{a} \qquad (4)$$

where K_{MH} and a are empirical coefficients. One important use of the relationship in Figure 1 is that it can be used to estimate the zero-shear viscosity of the dispersion of a food polymer when the polymer concentration and intrinsic viscosity are known. In addition, exponential and power law models can be used to describe the influence of soluble (e.g., °Brix) and insoluble solids (e.g., the pulp content of fruit juices) on the viscosity of processed foods (e.g., fruit juices and purees).

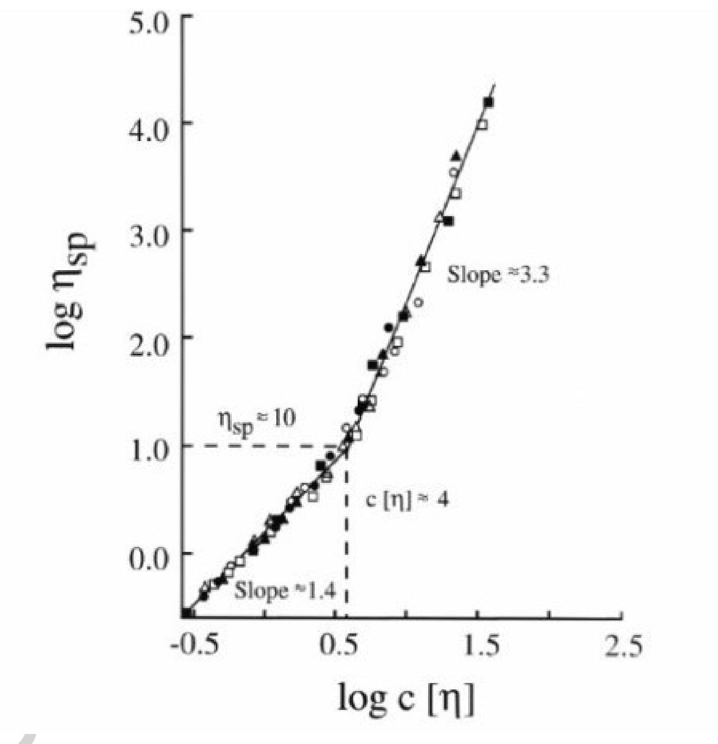

Figure 1. Variation of specific viscosity based on the zero-shear (Newtonian) viscosity of biopolymer dispersions with the coil-overlap parameter: ❍ dextran; ℓ carboxymethylamylose (0.5M NaCl, pH7); △ high mannuronate alginate (0.2M NaCl, pH7); ▲ high guluronate alginate (0.2M Na Cl, pH7); � (hyaluronate (0.015M NaCl; pH7); ☐ lambda carrageenan (0.075 M KCl; pH7).
[From: Morris E.R., Cutler A.N., Ross-Murphy S.B., and Rees D.A. (1981). Concentration and shear rate dependence of viscosity in random coil polysaccharide solutions. *Carbohydrate Polymers* **1**, 5-21.]

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Biographical Sketch

M. A. "Andy" Rao is a Professor of Food Engineering at the Geneva, NY campus of Cornell University. His research focus is on the measurement and interpretation of viscous and viscoelastic properties of fluid foods, thermal processing of solid and liquid foods, and unit operations in the preservation of fruit and vegetable products. Many original review papers and book chapters by Rao and his co-workers have resulted from these studies, including the book: Rao, M. A. (1999). *Rheology of Fluid and Semisolid Foods: Principles and Applications*, pp. 433, Aspen Publishers, Inc. Andy serves as Scientific Editor of the *Journal of Food Science*, and was elected as a Fellow of the Institute of Food Technologists in 1997.