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Rheology for the food industry

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Abstract

Rheological measurements are quite relevant in the food industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing, and for finished foods. There are several approaches to conduct these rheological characterizations, and the selected technique pretty much depend on the specific product and the functional characteristics in need to be analyzed. Several different types of equipments are available to scientists as a tool in food rheological studies leading to acceptable results in most design situations. This paper will focus on the review and discussion of some of the most relevant rheological tests of current interest to the food industry in selected examples, i.e. gels and emulsions.

Keywords: Rheology; Food; Viscosity; Rheometer; Deformation; Flow

1. Introduction

The science of rheology has many applications in the fields of food acceptability, food processing, and food handling (Barbosa-Cánovas, Kokini, Ma, & Ibarz, 1996). Foods, however, are complex materials structurally and rheologically and, in many cases, they consist of mixtures of solids as well as fluid structural components (Finney, 1972).

Rheology concerns the flow and deformation of substances and, in particular, to their behavior in the transient area between solids and fluids. Moreover, rheology attempts to define a relationship between the stress acting on a given material and the resulting deformation and/or flow that takes place.

Rheological properties are determined by measuring force and deformation as a function of time. The difference between fundamental and empirical rheological methods is that, unlike the latter, the former accounts for the magnitude and direction of forces and deformations, placing restrictions on acceptance of sample shapes and compositions. Fundamental tests have the advantage of being based on known concepts and equations of physics. Empirical methods are often used when sample composition or geometry is too complex to account for forces and deformations. These methods are of value if they correlate with a property of interest, whereas fundamental tests determine true physical properties.

Rheology is concerned with how all materials respond to applied forces and deformations. Basic concepts of stress (force per area) and strain (deformation per length) are key to all rheological evaluations. Stress (σ) is always a measurement of force per unit of surface area and is expressed in units of Pascals (Pa). The direction of the force with respect to the impacted surface area determines the type of stress. Normal stress occurs when the force is directly perpendicular to a surface and can be achieved during tension or compression. Shear stress occurs when the forces act in parallel to a surface.

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On the other hand, strain represents a dimensionless quantity of relative deformation of a material. The direction of the applied stress with respect to the material surface will determine the type of strain. Normal strain (ε) occurs when the stress is normal to a sample surface. Foods show normal strain when compressed (compressive stress) or pulled apart (tensile stress) (Nielsen, 1998).

Unique rheological properties of various foods have been reported and summarized in many publications (Rao & Steffe, 1992; Steffe, 1996; Steffe, Mohamed, & Ford, 1986; Weipert, Tscheuschner, & Windhad, 1993). However, published values for foods may not be accurate since factors such as variety, ripeness, processing methods, compositions, temperature, time, analytical assumptions, instrumental techniques, and analytical methods may influence rheological properties.

2. Rheological characterization of food gels

Some of the most popular foods, such as gelatin desserts, cooked egg whites, frankfurters, surimi based seafood analogs, and fruit jellies, can be considered gels. A gel is a solid-in-liquid colloid in which the solid phase forms a network structure that immobilizes the liquid and produces solid-like properties. A gel can also be described as a substantially diluted system that exhibits no steady state flow. The initial state can be a solution, dispersion, or suspension. Some food gels are formed irreversibly by cooking, while others like gelatin form reversible gels. Gelation arises either from chemical cross-linking by way of covalent reactions or from physical cross-linking through polymer-polymer interactions. The macromolecular substances responsible for network formation in food systems are primarily polysaccharides and proteins. The unifying property among these foods is that they are mostly fluids but respond as viscoelastic solids with a high degree of elasticity (Hamann, 1992; Hvidt & Heller, 1990; Nijenhuis, 1990). They usually fracture rather than flow when deformed. Fracture is inherent in sensory biting and mastication of foods so it is important to relate the fracture character of gels to their sensory texture.

Fracture properties are determined by deforming a sample to the point of abrupt mechanical yield (sometimes referred to as failure or ultimate properties). Deforming forces can be applied to gels during shear, compression, or tension. Shear changes the shape of a specimen but does not change volume. Tension tends to increase volume and compression tends to decrease volume. When compressive or tensile forces on a specimen are limited to a single direction they are termed 'uniaxial', differentiating them from forces causing bulk changes such as hydrostatic pressure (equal force per unit area applied perpendicularly to the specimen surface at all points on the specimen surface), which changes the volume but not the shape of a specimen. Uniaxial tension or uniaxial compression can change both shape and volume.

There are methods for determining fracture properties of foods based on uniaxial compression, uniaxial tension, or torsion. Of these methods, uniaxial compression is the most commonly used method because it does not require attachment of the specimen to the testing machine and several suitable commercial machines are available to perform the test. Most machines capable of uniaxial compression testing can also be used to deform samples in uniaxial tension; however, tension requires a strong attachment of the specimen to the machine, which can be difficult with food samples. Torsional testing of fracture properties also requires a strong attachment of the material to the machine and, until recently, no commercially produced machine has been available specifically designed for torsion testing of food samples. Commercial availability of testing machines and minimal sample preparation have made uniaxial compression testing methods dominant in determining fracture properties. However, the limitations of uniaxial compression testing may make it advantageous in some situations to utilize methods that deform samples in tension or torsion.

During processing, manufacture, and consumption of food, these gelled systems are subjected to large deformations that may cause the food either to deform irreversibly or to fail in fracture. This calls for a profound knowledge of their mechanical properties, as well as appropriate quality control measurement systems (Pons & Fiszman, 1996). Traditionally, single point measurements such as "gel strength" have been used by suppliers and users to characterize gel systems. However, these single point measurements, often based on rupture tests, are not representative of the overall mechanical behavior of gels. Gels are differentiated from other structured network systems, in which small portions of solids are dispersed in relatively large proportions of liquid, by the property of mechanical rigidity or the ability to support shearing stress at rest. Gel, which consists mostly of fluid, has the remarkable ability to behave as a solid while retaining many characteristics of the properties of the fluid components (Mulvihill & Kinsella, 1987). To evaluate the rheological properties of gels many considerations should be taken into account; one is related to composition. For example, in the case of gels formed from protein-polysaccharide mixtures, they are dependent on thermodynamic and structural compatibility between both macromolecules. Depending on the experimental conditions, both macromolecules can gel separately in a single phase (mixed gel) or one of the macromolecules gels and the other component can be dispersed as a filler (filled gel) (Embola, Swanson, Barbosa-Cánovas, & Luedecke, 1996).