Food Rheology using Dynamic Mechanical Analysis; A short review.

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Abstract

An ideal elastic material will deform finitely and recover its original shape and size upon the removal of the applied deforming load. On the other hand an ideal fluid will deform and continue to deform as long as the deforming load is applied, and finally the material doesn't recover from that deformation even when the load is removed. These two responses are termed as 'elastic' and 'viscous' respectively. Most materials, exhibits an intermediate viscous and elastic behavior and are referred to as "viscoelastic". A good example of such materials are polymers. In addition almost all foods, both liquid and solid, belong to this group. The viscoelasticity of materials can be determined by transient or dynamic methods. The transient methods are two pronged; stress relaxation which is the application of constant and instantaneous strain and measuring decaying stress with respect to time and creep which is the application of constant and instantaneous stress and measuring increasing strain with time. The transient methods are easy to perform, however, they are limited in the sense that the material response cannot be determined as a function of frequency. The dynamic methods are performed applying a small sinusoidal strain (or stress) and measuring the resulting stress (or strain). Due to the enormous list of advantages of performing dynamic tests, the method has been very popular in polymer studies for many years. This brief review demonstrates that the method has found a now increasing usage, especially in the last two decades, in studies of food, what has been referred to as Food Rheology.

Key Words; *Rheology, Viscoelastic, Viscous, Modulus, Food, Dynamic Mechanical Analyis*

1. Introduction

Rheology, which is applicable to all materials from solids to gases, is the science of flow and deformation of matter and describes the interrelation between force, deformation and time. Initially scientists found the need to describe fluid flow properties and Rheology as a science was found. In this context, food rheology is defined as the study of the deformation and flow of the raw materials, the intermediate products and the final products of the food industry. Currently, food rheology is used to describe the consistency of different food products, normally by the two components: viscosity and elasticity. Generally viscosity means resistance to flow or thickness and elasticity means the stickiness or structure. In food rheology, it has been found that many structural factors influence the rheology of foodstuffs. In addition to this, a change in processing variables [1, 2] influences the above-mentioned structural factors, leading to very different rheology behaviors for the same formulation. Therefore rheology plays an important role in food manufacture and marketing processes, beginning from design of handling systems, quality control and evaluation of sensory stimuli associated with oral and non-oral evaluation of viscosity [3, 4].

In food rheology the following parameters are useful and measured, i.e viscosity, Newtonian fluids, Non-Newtonian fluids, Laminar and turbulent flow. It is known that a host of factors affect these rheological parameters and include, Temperature, Shear rate, Measuring conditions, Time, Pressure, Previous history, Composition additives among other factors. This paper presents a brief review of the use of Dynamic Mechanical Analysis in food Rheology, which is a method that measures the Viscoelastic parameters of foods.

2. Viscoelastic Parameters of Foods

Dynamic mechanical Analysis is a non-destructive analytical method, meaning, it can be used to determine the viscoelastic properties of foods without altering the material structure [5]. Primarily the method is based from the fact that for viscoelastic materials, the resultant material sinusoidal stress response lags in phase/time from an applied sinusoidal strain by an angle δ. In such experiment, a sinusoidal oscillating stress or strain with a frequency ω is applied to the material and the phase difference between the oscillating stress and strain as well as the amplitude ratio are measured. The generated stress (σ_0) is expressed in terms of the storage modulus G' (Pa) and a loss modulus G'' (Pa). The storage modulus G' is a measure of the magnitude of the energy that is stored in the material i.e. the elastic response of the material. The loss modulus G'' is a measure of the energy which is lost as viscous dissipation per cycle of deformation i.e. the non-elastic response of the material [6]. The phase angle δ ranges from 0 to $\pi/2$ as the viscous component increases [7]. When the Loss modulus is greater than the storage modulus, the Food material is interpreted to be predominantly viscous and when the storage modulus is greater than the loss modulus, the material is behaving predominantly as an elastic solid. The ratio of the loss modulus to the storage modulus gives insight into the elastic and viscous character of the foodstuffs [8, 9, and 10]. In a graph of storage modulus versus frequency, the storage modulus at low frequencies characterizes the presence of structural relaxations in the material, which are completely absent when the slope is equal to zero and a plateau for the storage modulus is obtained [10]. The critical strain amplitude, indicating the maximum strain in the linear viscoelastic region, provides the maximum deformation amplitude that can be applied without affecting the dynamic moduli and thus the structure [8, 10, and 11].

Dynamic mechanical analytical tests done within the linear viscoelastic range i.e. at low amplitudes provides a simple measure of a food, such as firmness, or a number of defined parameters, such as hardness, adhesiveness and springiness [7, 12]. Hardness is defined as the peak force during the first compression cycle, adhesiveness is defined as the negative force area for the first cycle, and springiness is defined as the height to which the food recovers during the time between the first and second compression cycles [13]. For the reasons that makes dynamic analytical methods popular and useful, the reader will find a review by Gunasekaran and Ak, 2000 very useful [14].

3. Dynamic Mechanical Analysis in Food Rheology

In the quest for a more quantitative and reproducible ways for characterizing food products, it has been demonstrated in a number of studies that Dynamic Mechanical Analysis (DMA), for example, can provide information about the mechanical properties of food and how they are affected by various processing and storage conditions. Its common knowledge that the processing and handling of food products can significantly affect the material's texture, flavor, and appearance. Earlier on the methods used to characterize the food properties were arbitrary and non-quantitative [15]. In this section, a brief review of the use of DMA to characterize food properties is discussed.

3.1. Characterization of Food by Dynamic Mechanical/ Rheological Properties

Viscoelastic properties measured by DMA, can be used to characterize Food. For example, Dynamic mechanical spectroscopy and steady-shear rheological tests were carried out to evaluate viscoelastic properties of commercial sweet potato puree infant food using a controlled stress rheometer. It was found that the sweet potato puree behaved like an elastic solid with the storage modulus being predominant over the loss modulus. In addition, both elastic and viscous moduli decreased with an increase in temperature Li and Yeh (2001), determined the swelling powers (SP) of 10 kinds of starches obtained from cereals, roots, tubers and peas measured at a temperature range 55-95ºC [16, 17]. They found that the swelling starch, such as corn and rice starch, yielded greater peak storage modulus (G'_{max}) in dynamic mechanical analysis. The corresponding loss tangent ($\tan \delta_{G'max}$) correlated, with $r^2 = 0.8$ fairly with SP measured at 75ºC. Effects of ingredients on rheological properties that often infers the quality characteristics can be done in Food [18]. In a review by Moelants et al., 2014, it was noted that, particle concentration, particle size, and particle morphology were found to be key structural elements determining the rheological properties of these suspensions comprising low amounts of starch and serum pectin [10]. Rheological properties measured in dynamic and steady flows and their comparisons has been extensively been applied and done to many diverse food materials [19-22]. Independent studies has applied Dynamic rheological measurements and analysis of starches [23] such as Waxy Maize starches [24] carrot starch [25] and Gelatinized Wheat Starch [26]. Recently it was suggested in some studies that the rheological relaxation spectra can be considered a signature of the viscoelastic properties of specific starch gels [27,28].

3.2.Food Dynamic Mechanical properties studied under storage conditions

In a study by Vittadini and Vodovotz, 2003, effects of adding soy ingredients to bread during a 7-days storage at ambient temperatures revealed that soy shifted the main thermal transitions to slightly lower temperatures and decreased its temperature range i.e. increased homogeneity. Their conclusion was that soy may play a role in modulating bread staling [29].

3.3. Dynamic Mechanical Analysis of Food blends

In an investigation of the suitability of pea flour for cracker biscuits production Kohajdová et al 2013 [13] , it was also found that incorporation of pea flour to cracker biscuits modified physical properties of final products. Viscoelastic properties of wheat/broad bean [30] spaghetti/edible legumes [31], bread and biscuits supplemented with flours of germinated and un-germinated legume seeds or mushrooms [32] among many others blends have been reported.

3.4. Effects of Food processing Conditions on Mechanical Properties

DMA can also be used, as has been done before, in investigation of effects of processing conditions to the dynamic mechanical /viscoelastic properties of food. Ma et al, 2011, studied those effects to the processing of lentil, chickpea, and pea flours [2]. Effects of temperature of dynamic rheology of honey [1] and others has been reported.

4. Conclusion

The theory of dynamic viscoelastic tests that have been known and used in polymer studies has found promoted and widespread use in dynamic rheological testing of foods. This has been attributed to the improvements of rheometer designs and the lowering of purchasing costs of rheometers. This is a direct consequence of advances in computer and instrumentation technology. The viscoelastic properties obtained at dynamic, steady and thermal conditions provides information not easily obtainable by other methods. The next frontier now lies in the ability to correlate the measured dynamic properties of foods at different stages of processing and storage to the various sensory quality attributes and some relevant functional properties.

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