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The analysis of the influence of xanthan gum and apple pectins on egg white protein foams using the large amplitude oscillatory shear method

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ABSTRACT

This research study analysed the rheological properties of fresh food foams based on egg white protein, and with the addition of apple pectins and xanthan gum. The rheological analysis was carried out using the large amplitude oscillatory shear (LAOS) technique. From the obtained results two types of Lissajous figures were constructed, describing the elastic and viscous properties. The obtained figures were subjected to geometrical decomposition, which resulted in the determination of the stress values characteristic of nonlinear purely elastic and purely viscous properties. The Fast Chebyshev Transform allowed for the calculation of the Chebyshev coefficients, and further detailed analysis of rheological behaviour of foams as a function of strain amplitude. The determination of the values of elastic and viscous Chebyshev coefficients allowed for the interpretation, with high resolution, of nonlinear rheological properties of the obtained foams.

1. Introduction

Foams hold a prominent place among various food systems (Balerin, Aymard, Ducept, Vaslin, & Cuvelier, 2007; Miyazaki, Wyss, Weitz, & Reichman, 2006); they are multi-phase (dispersed) media, consisting of a liquid or continuous phase, in which a gas phase or air bubbles are dispersed. Their applications range from products such as ice creams, whipped cream or mousse, to baked goods (Perez, Sanchez, Rodriguez Patino, Rubiolo, & Santiago, 2012). The main purposes for foaming food products are: reduction of the product's density, diminishing its caloric value, modification of its texture and rheological properties (Liszka-Skoczylas, Ptaszek, & Żmudziński, 2014; Żmudziński et al. 2014), as well as improvement of its sensory features (Perez et al., 2012). The food foams prepared with egg white protein as a base constitute quite a wide-ranging group of foams. The egg white protein comprises high amounts of ovoalbumin, ovotransferrin and lysozyme (Al-Hakkak & Al-Hakkak, 2010) and has excellent foaming capabilities (Foegeding & Davis, 2011; Van der Plancken et al. 2007). Owing to these properties, the egg white protein is frequently used in the production of a variety of cakes and meringues (Van der Plancken et al. 2007).

Due to their thermodynamic instability, foams tend to disintegrate over time (Indrawati, Wang, Narsimhan, & Gonzalez, 2008; Makri & Doxastakis, 2006; Sollich, 1998; Sollich, Lequeux, Hébraud, & Cates, 1997; Stevenson, 2012). For this reason, various stabilizers are applied to the technological processes (Campbell & Mougeot, 1999; Dickinson, 2003; Miquelim, Lannes, & Mezzenga, 2010). In the case of using hydrocolloids (xanthan gum or pectins) (Miquelim et al. 2010; Prins, 1988), the foam stabilization is a result of increased viscosity of the continuous phase (Ka Lau & Dickinson 2007; Mleko et al., 2010; Mleko, Kristinsson, Liang, & Gustaw, 2007; Patino & Pilosof, 2011; Ptaszek, 2014; Thakur at al. 2003).

The addition of these hydrocolloids causes the foams' rheological properties to become quite complex; their flow starts to deviate strongly from the Newton's law and nonlinear behaviours begin to occur. The reason for these non-linear behaviours, characteristic of most food liquids, is the dependence of viscosity on the conditions

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and the duration of the shear process. Moreover, food products may constitute viscoelastic systems, exhibiting the characteristics of multi-phase liquids or solids, eg. biopolymer solutions, dough or starch paste-based products. These systems become viscoelastic due to being composed mainly of biopolymers, whose molecular structures are capable of both storing, as well as dissipating of mechanical energy (Ferry, 1980).

Until now, the research of these kinds of systems has been usually conducted in the linear viscoelasticity range – in the time and frequency domains.

More recently, methods expanding the capabilities of classical studies on frequency have gained the attention of scientists. The methods are: Large Amplitude Oscillatory Shear (LAOS) (Hyun, Nam, Wilhellm, Ahn, & Lee, 2006; Klein, Spiess, Calin, Balan, & Wilhelm, 2007) and Fourier Transform Rheology (FTR) (Hyun & Wilhelm, 2009; Hyun et al. 2011), and they consist of subjecting the material to deformations that are sinusoidally variable within time and exhibit sufficiently high amplitude (γ_0):

$$\gamma(\omega t) = \gamma_0 \sin(\omega t) \tag{1}$$

Under nonlinear conditions, the response of the material (stress) can be estimated with high accuracy using the following harmonic function:

$$\tau(t;\omega,\gamma_0) = \gamma_0 \bullet \sum_{n:odd}\left[G_n^{'}(\omega,\gamma_0) \bullet \sin(n\omega t) + G_n^{''}(\omega,\gamma_0) \bullet \cos(n\omega t)\right] \tag{2}$$

In the case of small strains there is only one harmonic present, and therefore G'_1 and G''_1 become real (G') and imaginary (G'') parts of the complex spring modulus ($G^* = G' + jG''$), well known from the studies of linear viscoelasticity (Ferry, 1980).

The analysis of the obtained function requires not only the application of an extended harmonic analysis based on the Fourier transform, but also a study using the phase plane (analysis of the Lissajous figures) (Hyun et al. 2011). The analysis based on the Lissajous figures in a 3-D coordinate system deserves particular attention (Ewoldt and Mckinley 2010). This 3D figure is created within a coordinate system illustrating relations of deformation (γ) to shear rate ($\dot{\gamma}$) and stress (τ). The obtained closed curve represents both elastic and viscous properties of the examined system. Such figure can be split into two projections in 2-D coordinate systems (Fig. 1), namely: elastic stress (deformation) ($\tau'(\gamma)$) and viscous stress (shear rate) $\tau''(\dot{\gamma})$ (Cho, Hyun, Ahn, & Lee, 2005). While the first figure describes the elastic properties of the system, the second figure represents the viscous properties. The described technique of separation into two 2-D Lissajous curves is based on the fact, that there is no possibility, in nonlinear area, to easily separate the obtained signal into two parts that would describe purely elastic or purely viscous behaviour.

The studies using the LAOS technique and the analysis based on the Chebyshev coefficients provide a new, and increasingly popular, approach to the analysis of food systems. This group of methods has been previously applied in tests of rheological properties of pastes and dough (Fuongfuchat et al. 2012; Ng & McKinley, 2008; Ng, McKinley, & Ewoldt, 2011), xanthan gum solution (Ewoldt et al. 2010) and O/W- as well as W/O-type emulsions (Ewoldt, Hosoi, & McKinley, 2008). The LAOS methods were also used to analyse the rheological properties of cheeses (Melito, Daubert, & Foegeding, 2012) and food foams, beers (Wilhelm, Reinheimer, & Kübel, 2012), and foams containing egg white proteins and non-starch hydrocolloids (Ptaszek, 2014, 2015). These methods allow for very high definition measurements of non-linear mechanical and rheological characteristics of substrates and food products. Another benefit of this approach is, that there is no need to use constitutive equations to isolate the purely viscous and purely elastic stresses in the non-linear range (Ewoldt et al. 2008; Saramito, 2007, 2009). Apart from research value, it allows for new possibilities in designing and modelling of innovative food products, according to consumer requirements. Therefore it seems quite beneficial to utilise the LAOS methods in the analysis of the rheological properties of food products.

In the case of previously described dispersed gas–liquid systems containing egg white protein and non-starch hydrocolloids (Ptaszek, 2014), we can expect various rheological behaviours. This is because the rheological properties of solutions containing proteins and hydrocolloids exhibit huge deviations from the Newton's Law. With the introduction of the gaseous phase into the system (eg. air), the rheological response of these systems during flow becomes even more complex. The analysis of these foams, as well as their behaviour in the non-linear range, seems to be of key importance, due to the increasing interest in the usage of hydrocolloids as stabilisers for foams derived from animal proteins.

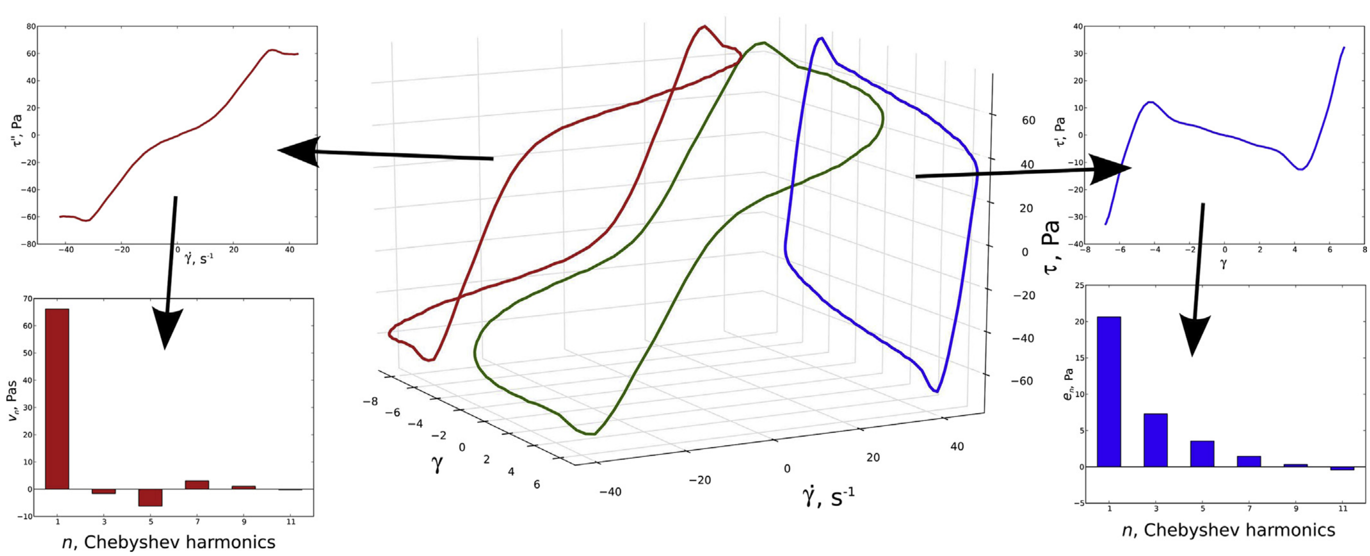

Fig. 1. Idea of decomposition of Lissajous figures.