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# The role of hydrocolloids in mechanical properties of fresh foams based on egg white proteins

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ABSTRACT

The paper presents results of studies on the preparation of fresh food foams based on egg white and hydrocolloids (xanthan gum and carrageenan). The basic physical parameters of the obtained foams such as density, gas volume fraction and size of gas bubbles were measured. Rheological measurements were also performed, and continuous Maxwell model was applied to describe viscoelastic properties. The analysis of the obtained results concerned the impact of individual hydrocolloids and their mixtures on the changes of the rheological properties as well as their influence on the stability of the obtained foams. It was shown, that addition of pure xanthan preserved native properties of the egg white protein foams; the resulting foams, however, created difficulties during further processing. Foams containing only carrageenan were unstable, but exhibited desirable rheological properties. As a result of mixing xanthan gum and carrageenan, stable viscoelastic foams with unique rheological and technological properties were obtained.



## 1. Introduction

Foam is a multi-phase system consisting of a liquid or solid continuous phase in which dispersed gas bubbles are suspended (Adamson and Gast, 1997). Currently, there is a great interest in fluid-gas systems of foam structure being observed. They are used for creation of new products or are applied as raw materials in food industry. One of the most often used foaming agents is egg white protein (ovalbumin).

The quality of the foam mainly depends on the conformation assumed by the emulsifier on the interfacial surface. In order to obtain stable foam, a protein molecule must be opened and its hydrophilic and hydrophobic groups must be activated. Moreover, a good foaming agent should be characterized by a good flexibility of its material molecule. In the case of egg white protein, it is done through the partial unfolding of macromolecules what enhances amphiphilic properties, which, in turn, facilitate the formation of foam. Foam, obtained in such a way, is unstable; hence it is necessary to stabilize it. Stability improvement of such foams is achieved through addition of low molecular weight compounds such as monosaccharides and disaccharides, or by addition of high molecular weight compounds – polysaccharides. Besides influencing stabilizing properties, addition of polysaccharides can also shape the rheological properties of the system (Miquelim et al., 2010). Viscoelastic properties are particularly crucial as they can be used in predicting many important technological parameters. Moreover, the viscoelastic properties are closely correlated with other physicochemical parameters of foam such as density or gas volume fraction.

Studies on the viscoelasticity of the foam produced on the base of egg white protein alone or with addition of polysaccharides are mainly focused on the analysis of the variability of the complex modulus in function of frequency (Mleko et al., 2007). Attempts have been also made to determine the influence of individual hydrocolloids on the viscoelastic properties of foams (Chávez-Montes et al., 2007). In addition, research on the broadly defined rheological properties of foams has been carried out (Lau and Dickinson, 2000). Problems related to the measurement of thixotropic properties of foams should be emphasized (Miquelim and Da Silva Lannes, 2009; Mleko et al., 2007).

The issues related to yield stress and nonlinear rheology frequently appear in the literature on rheological properties of foams (Rouyer et al., 2005; Weaire, 2008; Hutzler and Weaire, 2011). Moreover, two constitutive equations for elastoviscoplastic systems, proposed by Saramito (Saramito, 2007, 2009), turned out to be highly efficient in describing of nonlinear rheological properties of foams (Cheddadi et al., 2008, 2012). In the works of

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Marmottant and Garnier (Marmottant and Graner, 2007) a rheological model of foam as a elastoviscoplastic solid was also presented, which made it possible to describe the changes of G′ and G″ values in the function of the deformation amplitude. Saint-Jalmes and Durian, who have examined the influence of gas volume fraction on rheological properties of wet foam, also obtained interesting results (Saint-Jalmes and Durian, 1999).

However, the professional literature lacks works related to the analysis of rheological and viscoelastic properties based on linear models. There is no application of Maxwell or Burger type viscoelastic continuous models used for description of the characteristic time values (such as relaxation or retardation) in foam systems, either. There is no literature data related to the scaling of the rheological properties of food foams against protein or polysaccharide concentration. The aim of this study was to analyze the viscoelastic properties of egg white protein foam supplemented with xanthan gum and carrageenan. The main focus was the estimation of stress relaxation spectrum based on the continuous Maxwell model. An attempt was also undertaken to associate the characteristic rheological values with other physical properties of obtained foams.

## 2. Materials and methods

### 2.1. Materials

The commercial food egg white protein (Ovopol, Poland) and the following food additives: mixture of carrageenan gums (CA) (Regis, Poland) and xanthan gum (XG) (Hortimex, Poland) were used in this research.

The protein content in egg white determined by the method of Kjeldahl was (83.87 ± 0.10)%. Molecular weights and polydispersity of hydrocolloids were determined chromatographically, details were described in earlier work (Ptaszek et al., 2009). For xanthan gum there were obtained: weighted molecular mass $M_w = (19.6 \pm 0.9) \times 10^5$ g mol$^{-1}$, number molecular mass $M_n = (0.022 \pm 0.001) \times 10^5$ g mol$^{-1}$, polydispersity 871 ± 40, and for carrageenan respectively: $M_w = (8.7 \pm 0.4) \times 10^5$ g mol$^{-1}$, $M_n = (0.55 \pm 0.08) \times 10^5$ g mol$^{-1}$, polydispersity 16 ± 3.

### 2.2. Preparation of foams

The proper amount of egg white dry matter was chosen according to the manufacturer's instructions. The pure egg white protein foam should be produced using water and protein in the ratio of 9–1. In the investigated foams, part of the protein was replaced with structure-forming hydrocolloids, so that the dry matter content would remain constant. For this purpose the proper amount of protein and hydrocolloid mixtures (Table 1) was dissolved in the desired amount of distilled water, then whipped in an industrial planetary mixer (FCM Stalgast, Poland), suitable for foam whipping. Rotation of stirrer was set to 1300 rpm. Based on preliminary tests, whipping time of 120 s was chosen.

In order to evaluate the impact of individual components on the foam parameters, the plan of the experiment included mixtures of content given in the concentration matrix displayed in Table 1.

**Table 1**
Concentration of egg white and hydrocolloids (w/w) in studied foams.

| | XG (%) | | | | |
|---|---|---|---|---|---|
| CA (%) | | 0.0 | 0.3 | 0.6 | 0.9 |
| | 0.0 | 9.1 | 8.8 | 8.5 | 8.2 |
| | 0.3 | 8.8 | 8.6 | 8.2 | 7.9 |
| | 0.6 | 8.5 | 8.2 | 7.9 | 7.6 |
| | 0.9 | 8.2 | 7.9 | 7.6 | 7.3 |

### 2.3. Density

Foam density was determined by weighing a fixed volume of foam (100 mL) placed in the graduated cylinder. For each experiment this measurement was made in ten repetitions at 23 °C.

### 2.4. Volume fraction of gas phase

Volume fraction of gas phase was determined using the following correlation:

$$\phi = \frac{V_f - V_l}{V_f} \tag{1}$$

where $V_f$ – foam volume, $V_l$ – volume of liquid.

These values were determined by measuring the foam volume and the volume of a liquid contained therein. In order to determine the amount of the disperse phase (gas) in the foam, its disintegration was performed in a laboratory centrifuge (5000g). Centrifugation was carried out at 23 °C until the complete destruction of the foam. The centrifugation was performed for 10 min and centrifugation time was independent of the composition of the continuous phase. For each foam this measurement was made in ten replications.

### 2.5. The size distribution of gas bubbles suspended in the liquid phase

The analysis of the size distribution of air bubbles suspended in the liquid phase was carried out with the use of an inverted optical microscope (Kozo, China) with the application of 4-fold and 10-fold magnification. The observed images were recorded with a digital camera and stored on the computer in TIFF format (with a resolution of 1280 × 1024 pixels).

The image analysis was performed using ImageJ program (http://rsbweb.nih.gov/ij/index.html). The data obtained in this way included surface area of air bubbles. In order to convert the surface given in pixels into diameter, the calculation on reference objects was performed. The calculations of equivalent diameter were performed assuming a perfect circularity of air bubbles (Junker, 2006):

$$d_i = \sqrt{\frac{4S_i}{\pi}} \tag{2}$$

On that basis, the size distributions of gas bubbles suspended in liquid were carried out and Sauter mean diameter ($d_{32}$) was calculated according to the Eq. (3):

$$d_{32} = \frac{\sum_{k=1}^{n} d_k^3}{\sum_{k=1}^{n} d_k^2} \tag{3}$$

For each foam 50–60 images were collected, which allowed to obtain a representative probe of a population of about 600 bubbles (Vigneau et al., 2000).

### 2.6. Rheological studies

Measurements were made using RS6000 rheometer (Haake, Germany). A cone-plate sensor was used. The cone parameters were as follows: diameter 60 mm, angle 1°. Measuring gap size was selected on the basis of preliminary studies, and adjusted to 3 mm. This was the highest value, at which repeatability of 95% was achieved. The size of the gap is important for the measurement of the properties of dispersed, foam-type, systems. The gap has to be selected so that gas bubbles are not crushed or destroyed.

Rheological studies relied on the measurement of the values of the complex modulus $G^*$ as a function of frequency, within the range of 0.1–10 Hz at 23 °C. The first step was to determine the