VOLUME EXPANSION OF CAKE DURING BAKING AND ITS INFLUENCE ON CAKE QUALITIES.

Michèle Marcotte. Food Research and Development Centre, Agriculture and Agri-Food Canada, 3600 Casavant Blvd West. St. Hyacinthe, Quebec, J2S 8E3, (marcottem@agr.gc.ca).

ABSTRACT

Located at the end of the processing line, baking is essential in the manufacturing of starchy products (e.g. breads, cookies, cakes). The operation leads to products with typically important technological macroscopic properties (e.g. moisture content, proper dimensions or yield, desired and appealing color, texture and taste). During baking, biochemical constituents undergo physico-chemical changes at microscopic level (e.g. phase transition, modification of structural properties etc.). Results of these changes are appreciable. As an example during baking, the dough/batter of starchy products increased and the macroscopic volume is expanding from the effect of the air incorporation (mixing), the production of CO_2 either by the chemical agent or by fermentation (proofing) and the water vaporization. For all starchy products, typical kinetic profiles are usually obtained: an increase up to around 2/3 to 2/4 of the baking time then a decrease to some extent. Without quantifying the relationship between the cellular structure and the molecular forces that govern its creation and stabilization, there is little hope of developing the process science that will permit us to control the formation of these man-made cellular solids (i.e. a solid matrix with an associated gaseous phase. The objective of the study was to analyze the main factors responsible for the generation of the expanded or porous structure during baking. More specifically, the amount (X) of a typical leavening agent (0, 1X and 2X) and 5 levels of constant baking temperatures (200, 225, 250, 275, 300^{o}C) were studied for their effect on volume expansion, color and texture (instrumental and sensory). Increasing the quantity of leavening agents did not necessarily result in a significant effect on volume expansion but the firmness of the resulting products was decreased. As expected, a slight increase of the temperature resulted in an increase of the volume expansion but an important elevation of the temperature resulted in a decrease of the volume accompanied by an intense surface color and an increase of the hardness.

INTRODUCTION

Cellular solids are “structures” comprised of a solid matrix and an associated fluid. If the fluid is gaseous, cellular solids have low densities. Many foods are cellular solids, either because nature made them so (fruits and vegetables), or mainly because they are processed into them (e.g., bread, cookies, cakes) to obtain desired or appealing textural properties. Cellular solids are alternatively named bubble foods.

The principles for studying the structure and properties of cellular solids were laid out by Gibson and Ashby (1997) and by Weaire and Hutzler (1999). A relationship was established between the Young’s modulus (an indication of the hardness of the structure) and the density as well as between the failure stress and the density as:

$$\frac{\varepsilon^*}{\varepsilon} = C_\varepsilon \left(\frac{\rho^*}{\rho}\right)^2 \text{ and } \frac{\sigma^*}{\sigma} = C_\sigma \left(\frac{\rho^*}{\rho}\right)^{1.5} \quad (1)$$

Where *C* is the parameter characterizing the microstructure, the * indicates the property of the cellular solid whereas the absence of * indicates only the property of the solids without bubbles. At first, food technologists applied these principles to develop consistent strategies for creating and controlling cellularity in extruded starch foams (Waterburton et al, 1990). To demystify structure-property relationships of cereal products, Emehdi et al. (2003) used the same principles. It is interesting to point out that the volume fraction occupied by gas bubbles in a final bread product may represent more than 50% of the total loaf volume (Scanlon and Zghal, 2001). However, the majority of the rheological studies on starchy products (Bloksma and Bushuk, 1988) have not viewed the presence of gas bubbles as an important area of investigation, despite their importance to the rheological properties of the processed dough/batter. Alternatively, Campbell et al. (1999) are viewing starchy product making as a series of aeration stages with published detailed results on number, size and distribution of bubbles during the proofing of bread. In their recent study, Babin et al. (2004) have shown that the Gibson and Ashby model could not explain satisfactorily the great dispersion of experimental data for extruded starches. The difference of mechanical properties for samples of same density could be explained by their inherent microstructure (number of bubbles, size and distribution). Other models were developed to describe volume expansion in other areas of research (Ramesh et al., 1991), for expansion of extruded products (Fan et al., 1994) and for bread baking (Fan et al., 1999). In these models, macroscopic volume expansion is related to the increase of the volume of individual gas bubbles inside the cellular solid. It is possible to describe the rate of bubble expansion as a function of the pressure difference between gas bubbles and the continuous phase taking into account the surface tension of the bubble and the product viscosity.

It is well recognized in the literature that there is not only a strong relationship between the formulation (choice and quantity of ingredients) and final product properties but also between processing conditions and final product properties (Baik et al., 2000ab). Moreover, the properties are influenced by the structure that may be evolving during processing. Due to a lack of knowledge, most of the research on these relationships is specific to a particular operation and product, and the relationships are established using a trial and error approach. The processing of a typical bakery product requires several steps including using the appropriate flour (the major ingredient that may change from year to year due to varying weather conditions, origin of the grain, cultural practices, grain milling processes etc.), adding other ingredients (e.g., sugar, fat, leavening agents, water etc.) by mixing (incorporation of air), forming, proofing (e.g. bread fermentation for CO_2 production) and final baking (e.g., air temperature, humidity and velocity in various ovens, moisture evaporation within the product) at the industrial plant. Variations at any of these steps (e.g., flour grain production, milling factory, bakery plant etc.) can affect one's ability to manufacture a bakery product of the final structure with desired macroscopic physical characteristics (e.g., consistent dimension, density, moisture content, surface color and texture). Industrial variability is experienced quite frequently (e.g., uncontrolled thickness of cookies, undesirable cake volcanoes, textural variations making the resulting cookies more brittle and fragile, bread or cookie dough sticking to the equipment during the forming process etc.). A typical bakery plant would like to control the product yield (i.e., the ratio of a given mass of product to its volume). On one hand, it is relatively easy to control the mass of product. This is performed on a routine basis as a quality control measurement. However, since the volume of a typical bakery product will expand significantly (4-10 times) upon processing (e.g., proofing, baking etc.), controlling the volume expansion (i.e., the yield) still remains an important difficulty. Currently, troubleshooting of these recurring variability problems is not an easy task and requires in-depth, hands-on practical experience. Because of a lack of basic understanding of the mechanisms involved, solutions are normally found using a trial and error approach that is quite time consuming and expensive (because of the quantity of raw materials needed), and will result in considerable product waste. Understanding the effect of ingredient selection and quantity and processing conditions on the resulting structure and properties during mixing, proofing and baking is therefore a key issue. The objective of this study was to quantify the volume expansion while varying baking temperatures and leavening agent concentration simultaneously in order to get a better understanding of the volume expansion phenomenon.

MATERIALS AND METHODS

Cake Batter Formulation

A typical AACC (American Association of Cereal Chemists) model formulation for white cake was used: water (870g, 31.3%), sugar (840g, 30.3%); flour (600g, 21.6%); shortening (300g, 10.8%); skimmed milk powder (72g, 2.6%); white egg powder (54g, 1.9%), leavening agents (22.37g, 0.8%) and salt (18g, 0.7%).

Cake Batter Preparation

The cake was prepared using a Hobart Mixer in 3 steps. At first, all ingredients were mixed with 522 g of water. The second and third steps consisted of adding 174 g of water. At every step, 4 pulses were applied. The first pulse was performed at the first speed level for 30 min. The subsequent pulses were performed for time duration of 4 min at the second speed level. Between every step, the bowl was swept using a hand scraper.

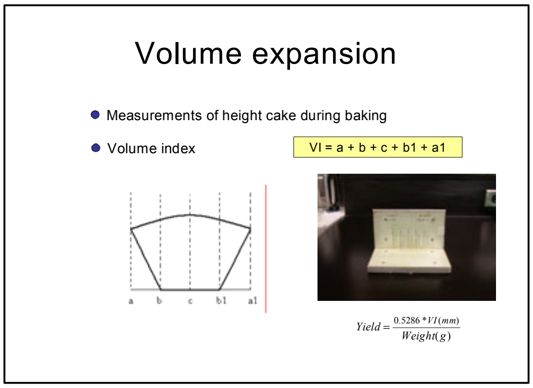
Baking Conditions and Oven

Five baking temperatures were applied (200, 225, 250, 275 and 300°C) and three amount of leavening agents (C) (i.e. without leavening agen or 0X, the recommended AACC amount or 1X, twice the AACC recommendation or 2X) were varied simultaneously for a total of 15 experimental conditions. Experiments were performed in duplicates. For each batch of batter, 16 molds (Cup Cake type) were filled. Molds were entered into a constant temperature batch oven (Figure 1) mounted on a scale. Weight losses were recorded continuously during baking. A typical value of cake batter initial moisture content was 33%. Baking times for each oven temperature conditions were determined to reach a final moisture content of 23-24% as being: 1) 1800 s at 200^{o}C; 2) 1340 s at 225^{o}C; 3) 1160 s at 250^{o}C; 4) 940 s at 275^{o}C and finally 5) 800 s at 300^{o}C. For verification, the final moisture content was determined at 23% and results were not significantly different for each baking time-temperature conditions at 5% level.

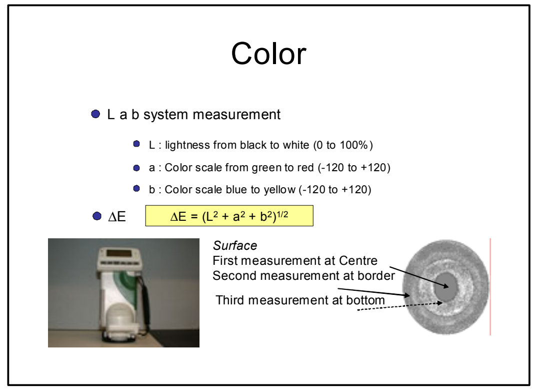
Figure 1: Baking Oven

Measurement of quality parameters

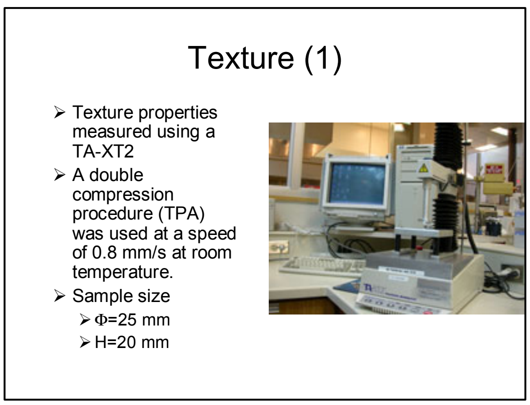
<u>Yield & Volume Index</u>

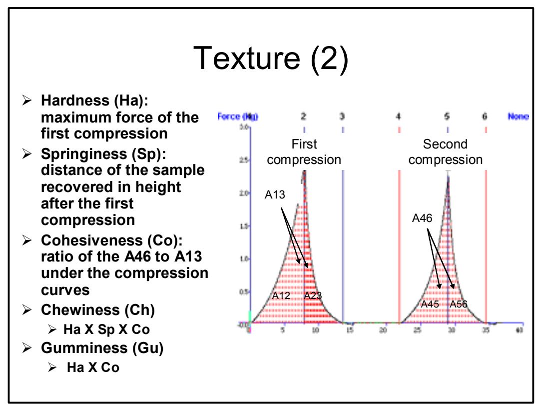


<u>Measured Color</u>



Texture parameters measured (chewiness, gumminess, hardness)





<u>Sensory Evaluation</u>

A limited sensory evaluation was performed for texture in mouth specifically for the hardness. A statistical analysis, a Friedman ranking test using 24 judges, was performed using the software FIZZ (version 1.30, Biosystemes, Couternon, France) at a level of significance of 5%.

RESULTS AND DISCUSSION

<u>Volume Expansion Kinetics</u>

Figure 2 shows the volume expansion kinetics at various temperatures. A typical increase was observed to reach a maximum volume. Then the cake volume decreased significantly. The height of the cake as well as the rate of increase is greatly affected by the baking temperature. These profiles are typically obtained for other bakery products such as bread (Kusunose et al., 1999) or cookies and are even similar to those obtained by for extruded products (Fan et al, 1994). A visual observation of the baking process demonstrated that the volume expansion ceased as soon as there is a significant crust formation at the surface. As well, the viscous batter is gradually becoming an elastic cellular solid. Bubbles expansion is reduced by the solidification of the structure.

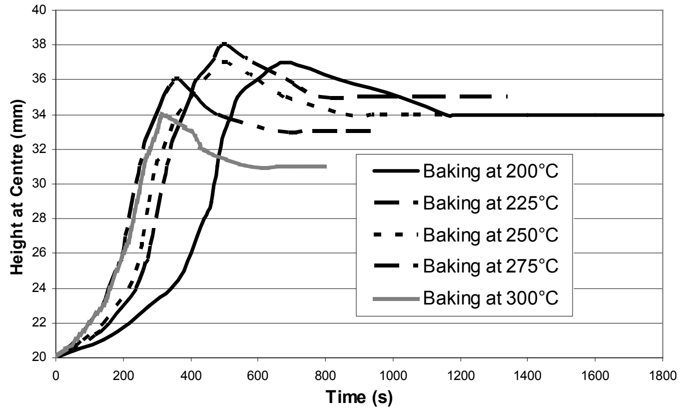


Figure 2: Volume expansion profile

Using a simplified model presented at the ASAE-CSAE meeting in Ottawa (Marcotte and Chen, 2004), simulations of macroscopic volume expansion were performed. The shape of the cake was assumed to be a cylinder. Modeled phenomena included: heat transfer, moisture transfer, gaseous production and cake volume expansion. Heat and moisture transfer phenomena were well described by Fourier's law of conduction with appropriate boundary conditions. Major assumptions included: 1) a uniform initial temperature and moisture for oven and cake; 2) a constant temperature and moisture during baking; 3) individual bubbles were lumped into a macro bubble; 4) gases inside the bubble followed the ideal law; 5) CO_2 production was assumed to follow a first order reaction kinetics and an Arrhenius type of behaviour for the effect of temperature. Volume changes were related to changes in temperature and pressure as:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \qquad [2]$$

The pressure (P) inside the bubble was assumed dependent on CO_2 pressure (P_c) and on vapour pressure (P_v). A Kelvin model, comprising both an elastic and a viscous element, was used to describe the volume expansion using the pressure difference. Figure 3 shows that predicted volume expansion was in accordance to experimental data at both 200^{o}C and 225^{o}C and that it was possible to predict very well the macroscopic volume expansion during the increasing part of the curve but it was not possible to describe the plateau and the decrease of curve.

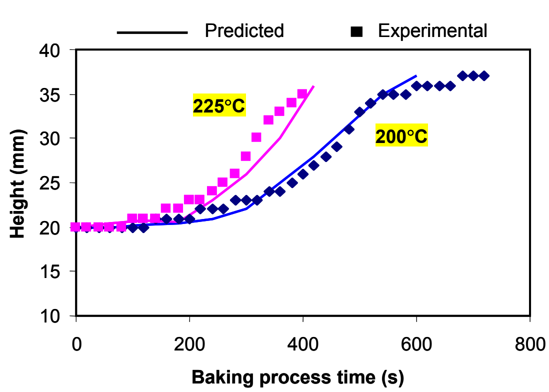


Figure 3: Predicted and experimental volume expansion

Volume Index

Figure 4a shows the volume index of various cakes as a function of baking temperatures and quantities of the leavening agent (0X, 1X and 2X). The volume index increased while adding leavening agents. Therefore it can be concluded that not only the water evaporation neither the air incorporation in the batter was sufficient to generate the desired volume although it resulted in a small increase of the volume. There is a limit in the amount of leavening agents that can be added to the batter as doubling the concentration did not result in a significant increase of the volume. An increase of the baking temperature did not necessarily result in an increase of the volume expansion. There seems to be an optimal value of baking temperature. This phenomenon might have also been linked to the crust formation (earlier at higher baking temperatures). In terms of volume expansion, best results were obtained for cakes (1X) baked at relatively low temperatures (200°C and 255°C). A maximum volume expansion was observed. As expected there was a strong interaction between the leavening agent concentration and the baking temperature.

Using the five measurement point of the volume index (a, b, c, a1 and b1), it was possible to evaluate the surface profile of the volume expansion and hence to identify any major defect that could occur during baking as seen in Figure 4b. A high baking temperature resulted in a reduced final height of cakes characterized by a flat shape. This phenomenon was even more important for cakes containing twice the concentration of the leavening agent.

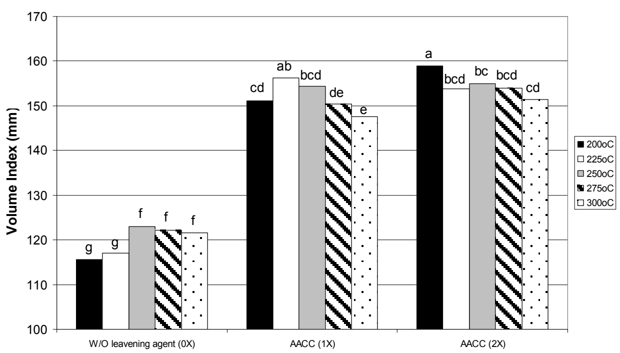


Figure 4a: Global volume index

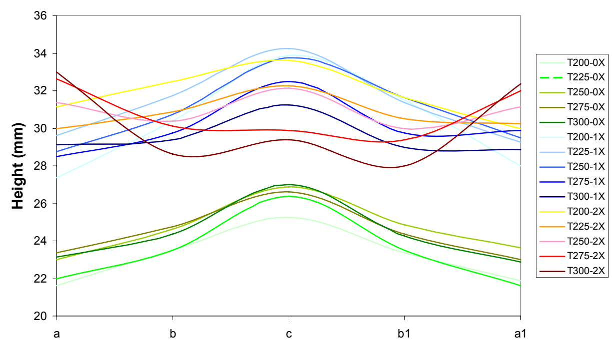


Figure 4b: Local volume index

Color Measurement

As observed in Figure 5, globally, an elevation of the baking temperature resulted in a decrease of the average ΔE. The presence or absence of the leavening agent did not affect significantly the final surface color of cakes. Increasing the concentration of the leavening agent resulted in a decrease of ΔE. This phenomenon is probably due to the degradation of sodium bicarbonate that accompanied an increase of the pH that resulted in a darker cake. Visual observation revealed that it was most uniform and typical of industrial caked while products were baked at lower temperatures.

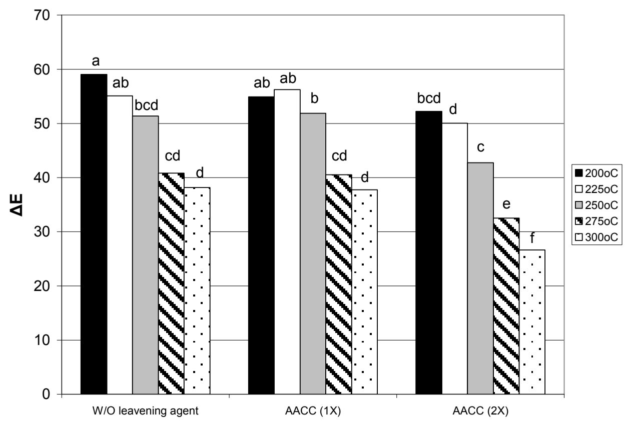


Figure 5: Average ΔE of cakes at various baking temperatures

<u>Texture parameters</u>

Hardness decreased as the concentration of the leavening agent increased due to the increase of porosity (Figure 6). Significant differences were obtained with respect to temperature for the AACC recommended concentration. Higher baking temperatures resulted in harder cakes. For a concentration of leavening agent that was doubled, baking temperatures did not have any significant effect on the hardness of cakes.

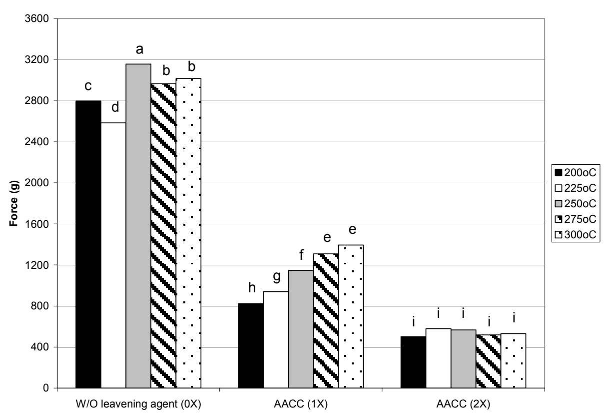


Figure 6: Hardness of a cake for various baking temperatures

<u>Sensory Evaluation</u>

Sensory evaluation is normally performed using a limited number of samples (3-5). From the results of hardness measurement using a TA-XT2, only samples with the AACC recommended concentration of leavening agents were presented. Since there was no significant difference between the hardness at 275 and 300^{o}C, judges evaluated only 4 samples baked at 200°C, 255°C, 250°C and 275°C. The performance of the judges is demonstrated in Figure 7. They were able to differentiate cakes cooked at 225°C, 250°C and 275°C based on their hardness but could not distinguish statisticallycakes baked at 200°C and 225°C. Fifteen and 7 judges ranked cakes baked at 200°C and 225°C as being less firm (rank 1) where 9 and 12 judges ranked cakes baked at 200^{o}C and 225^{o}C as being second (rank 2) in terms of hardness. Cakes baked at 275°C were found to be the hardest (rank 4) by 19 judges and 16 judges were able to rank cakes baked at 250°C as the third (rank 3) in terms of hardness. Results were well correlated with those obtained with the instrumental analysis (TA-XT2) as harder cakes were found if baked at higher temperatures. Preferred samples were those baked at 200°C and 225°C. Panellists were found to be quite sensitive for the cake texture evaluation.

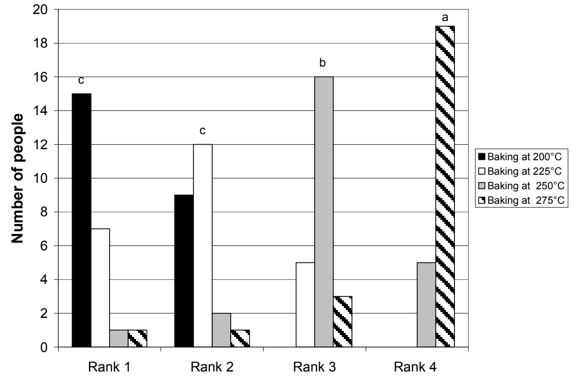


Figure 7: Sensory evaluation performance of judges (24) for cakes.

CONCLUSIONS

A certain amount of leavening is necessary to obtain an appropriate volume expansion. Increasing the amount of leavening agent did not influence positively the volume expansion. It resulted in some shape defect and surface color darkening. A slight increase of the baking temperature had a positive effect on the volume expansion but an important increase resulted in a decrease of the volume expansion. An elevation of the baking temperature resulted in a decrease of the average ΔE. A strong interaction was found between baking temperature and concentration of leavening as for their effect not only on cake volume expansion but also on instrumental analysis of the cake hardness. The sensory evaluation of hardness was correlated to the instrumental measurements. Experimental data of the volume expansion kinetics matched predicted volume expansion data for the first ascending part of the curve using an in-house simplified model. However, it was not possible to describe the entire volume expansion kinetics.

REFERENCES

[1] Babin et al. (2004) X Ray Tomography Investigations of Extruded Starches: Relationships between Process, Structure and Properties. Poster presented at the 9th International Conference on Engineering and Food. March 7-11. Montpellier.
[2] Baik et al. (2000a) Food Res. Intl. 33: 587.
[3] Baik et al. (2000b) Food Res. Intl. 33: 599.
[4] Bloksma et al. 1998. *Wheat: Chemistry and Technology.* Vol. II:131.
[5] Campbell et al. (1999). Bubbles in Food. Eagan Press. St. Paul Minnesota, USA.
[6] Elmehdi et al. (2003). J. Cereal Sci. 38: 33-42.
[7] Fan et al. (1994) J. Food Eng. 23:337.
[8] Fan et al. (1999). J. Food Eng., 41: 69.
[9] Gibson, L.J., Ashby, M.F. (1997). Cellular Solids: Structure and Properties. 2nd Edition. University Press. New York.
[10] Kusunose C., Fujii T., Matsumoto H. 1999. Role of starch granules in controlling expansion of dough during baking. Cereal Chemistry, **76**(6), 920-924.
[11] Marcotte, M., Chen, C.R. 2004. A Computer Simulation Program for Cake Baking in a Continuous Industrial Oven. Oral Presentation. Session: 303/610 Mathematical Modeling in Food Process Engineering. 2004 ASAE/CSAE Annual International Meeting. Ottawa, Ontario. August 1-4.
[12] Ramesh, N. S., Rasmussen, D. H., and Campbell, G. A. (1991). Numerical and experimental studies of bubble growth during the microcellular process. Polym. Eng. Sci., 31 : 1657-1664.
[13] Scanlon and Zghal, 2001. Food Res. Intl 34(10: 841.
[14] Waterburton et al., 1990. J. Mater. Sci. 25:4001
[15] Weaire, D.L., Hutzler, S. (1999). The Physics of Foams. Clarendon Press. New York.