Journal of Food Engineering 170 (2016) 1–7

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

The effects of using a direct electric current on the chemical properties of gelatine gels and bacterial growth

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ARTICLE INFO

Article history:
Received 29 October 2014
Received in revised form
22 July 2015
Accepted 12 August 2015
Available online 21 August 2015

Keywords:
Preservation
Staphylococcus aureus
Yersinia enterocolitica
Direct current
Storage
Gelatine

ABSTRACT

This article comprises an investigation of the changes within the chemical properties of gelatine samples with different sodium chloride concentrations (0; 0.5; 2% w/v) that were caused by applying a direct current (DC). The pH and chloride ion concentration were measured during the storage period of 7 days, and litmus was used to visualise pH changes. Additionally, the effect of a weak DC (10, 20 and 30 mA) on the growth of *Staphylococcus aureus* and *Yersinia enterocolitica* was analysed. The results measured after the storage time indicated little pH change on the anode side of the gelatine samples with 0.5 and 2% NaCl; however, the pH was considerably reduced near the cathode side where the sodium ion concentration decreased by 34–39%. Furthermore, the application of DC inhibited bacterial growth, and this effect was strengthened by the addition of sodium chloride. This work demonstrates that the use of DC in hydrogels is a promising method of food preservation, but requires further investigation.

1. Introduction

Food borne diseases are significant causes of morbidity and economic loss. This problem was emphasised in 1983 by the Joint FAO/WHO Expert Committee on Food Safety who concluded, “illness due to contaminated food is perhaps the most widespread health problem in the contemporary world and an important cause of reduced economic productivity” (WHO, 1984). More recent data also show that food borne diseases still exist (Batz, 2013, Sockett, 2014).

The most commonly used food processing technologies aimed at microbial destruction are the traditional thermal methods (e. g. pasteurisation, sterilisation, drying and evaporation) (Vicente and Castro, 2007); however, the use of increased temperatures can cause protein denaturation, reduce the vitamin content and cause a loss of volatile flavour, which leads to a deterioration of food quality (Pardo and Zufia, 2012).

Consumers are increasingly aware of the limitations of commonly used food preservation methods. Consumers tend to choose safe, high quality unprocessed products. To fulfil these requirements, the food industry is looking for new, more effective methods of food preservation that are not hazardous to consumer health and that only minimally influence the physicochemical properties of the products (Ramos et al., 2013).

During the last decade, non-thermal technologies have been intensively developed. The use of temperatures lower than those occurring during thermal pasteurisation causes no or minimal changes to the product (Morris et al., 2007, Wan et al., 2005). Furthermore, thermal preservation treatment is one of the most energy consuming processes in food production (Pardo and Zufia, 2012), while non-thermal food processing methods lead to considerable production cost savings (Morris et al., 2007).

The newly investigated inactivation technologies include ionisation, radiation, high hydrostatic pressure (HHP), high pressure homogenisation, UV decontamination, pulsed high intensity light, high intensity laser, pulsed white light, high power ultrasound, oscillating magnetic fields (Devlieghere et al., 2004), and methods utilising electric current, e.g., pulsed electric fields (PEF) (Huang et al., 2012), cold plasma (Gurol et al., 2012) and electrolysed water (Liu et al., 2013). Despite their many advantages, these methods have also flaws. The main challenges for the commercialisation of these technologies include consumer acceptance, lack of suitable industrial scale processing units for ultrasound processing, the shadowing effect in UV light processing and facility set-up for ionising radiation (Misra et al., 2014).

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http://dx.doi.org/10.1016/j.jfoodeng.2015.08.017
0260-8774/

The effect of an electric field on bacteria has been studied for several decades. Bacterial viability, metabolism, and movement have been tested. The use of very high-pulsed voltage for sterilisation purposes was investigated (Sale and Hamilton, 1967; Mizuno and Hori, 1988). PEF technologies have already been used in industry with promising results; however, PEF can only be used for liquid food (Suzuki, 2002).

The flow of a weak DC may be used in the food industry as a new food decontamination method. One possible application of the method described in this article and mentioned in patent US20120119759 is food conveyance equipment or food dryers in which food is subjected to DC. In an alternative setup, food that is to be treated may be passed through a water bath, tank or chamber subjected to DC. The authors believe that the use of a DC flow in the hydrosol layer can also be used for new active packaging material preparation. Food-based biopolymer materials have been successfully used to produce edible packaging. One of the oldest and most popular examples of this is the use of gelatine in manufacturing sausage casings (Liu et al., 2005). During the past decade, active packaging has become one of the major areas of research in food packaging. Among these active packaging systems, the antimicrobial version is of great importance (Coma, 2008).

The aim of this study was to evaluate the changes in the pH and chloride ion concentration measured in hydrogel gelatine blocks after the application of a direct electric current (DC) and to determine the antibacterial activity of DC.

2. Materials and methods

2.1. Preparation of hydrogel gelatine samples

Gelatine from porcine skin (180 Bloom) purchased from Weishardt (Graulhet, France) was used in all of the experiments. The prepared hydrosols contained 8% (w/v) gelatine and 0, 0.5 or 2% (w/v) NaCl. Then, the sols were heated to 60 °C and stirred continuously for 10 min. The samples were poured into glass beakers and were placed in a refrigerator (3 °C) for 24 h. After removal from the beakers, the cylinder-shaped hydrogel blocks with a base diameter of 40 mm and height of 30 mm were treated with DC.

2.2. pH and chloride ion concentration

The apparatus used to treat the gelatine samples and measure the pH and chloride ion concentration before and during storage is presented in Fig. 1. The electrodes were kept in contact with the opposite surface of the gels at the centres of the top and bottom of the sample base (Fig. 1). For all of the experiments, the electric current was provided from a DC power supply, Major Science MP-SAP. The amperage of the current and the time of exposure are shown in Table 1. Titanium electrodes coated with platinum in the shape of a bar with a diameter of 2 mm were used. The anode tip was ball-shaped (diameter 3 mm), while the cathode tip was cone-shaped.

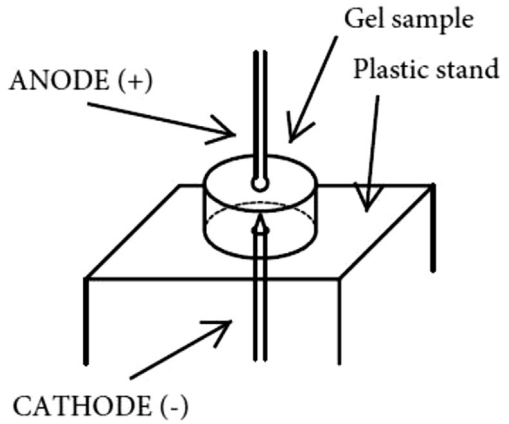

Fig. 1. Electrification apparatus used for the analysis of the chemical properties.

The pH was measured on the surface layer of the gels where the electrodes were applied using an electrode connected to a pH meter- HI 99161. The chloride ion concentration was measured in the geometric centres of the gels using a pH/mV/ISE Meter (Seven Multi™ model S40 Mettler Toledo) equipped with a chloride electrode (DX235) and a Reference Electrode (Inlab References Pro). The samples were stored in a refrigerator (4 °C) for 7 days. The chloride concentration and the pH of the hydrogels were measured on storage day 0, 3 and 7.

For all of the experiments, the controls were treated in exactly the same manner as the research sample, except that no electric current was applied.

2.3. Visualisation of changes in the pH

Hydrosols containing 8% (w/v) gelatine, 0 or 0.5% (w/v) NaCl and a litmus indicator solution (0.05% w/v) were prepared. The gel samples obtained as described in point 2.1 were subjected to DC. The parameters of the applied current are shown in Table 2. The electrodes and places of their application were identical as described in point 2.2.

A longitudinal section was cut from the gelatine gels. Then, the diameter (d) and depth (r) of the areas where the changes in the pH had been observed were measured. The above-mentioned parameters were encoded as follows: the anode side-d_a, r_a and cathode side-d_c, r_c (Fig. 2).

2.4. Microbiological analyses

A plate diffusion test was used to determine the effect of DC on *Yersinia enterocolitica* PCM 2080 and *Staphylococcus aureus* PCM 2602. These microorganisms were obtained from the culture collections of the Institute of Immunology and Experimental Therapy, Polish Academy of Sciences. The bacterial cultures were grown on Nutrient agar slants and kept at 4 °C. *Y. enterocolitica* and *S. aureus* inoculum were prepared by growing the cells in enriched broth (Sigma Aldrich, Poznań, Poland) at 37 °C for 24 h. The visible absorbance of the bacterial culture was measured using a UV 1800 spectrophotometer (Rayleigh Instruments Limited, England) at 550 nm. Two types of media were prepared: a standard medium without sodium chloride and an experimental medium containing 0.5% (w/v) NaCl. The agar plates were inoculated with 10^6 CFU/mL of bacterial cultures. When the medium was completely gelled, the plates were inverted and a hole for the cathode was melted in the

Table 1
The conditions of the gel system electrification for measuring the pH and chloride ion concentration in the gelatine blocks treated with DC.

Run code letter	Current [mA]	Time [min]
C200T1	200	1
C200T5	200	5
C200T15	200	15
C400T1	400	1
C400T1	400	5
C400T1	400	15
C800T1	800	1
C800T5	800	5
C800T15	800	15