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Effect of pulsed electric field processing parameters on *Salmonella enteritidis* inactivation

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Abstract

Pilot scale continuous pulsed electric field treatment of liquid products was tested on the effects of energy input ($0 < Q < 300$ kJ kg^{-1}), electric field strength ($25 < E < 70$ kV cm^{-1}), square wave pulse width (0.05, 0.1, 0.25, 0.5, 1, 2 and 3 μs) and initial product temperature ($4 < T_{INIT} < 20$ °C) on *Salmonella enteritidis* inactivation in a model solution composed of 28 mM sodium sulfate and 28 mM glucose.

For $Q = 0$–100 kJ kg^{-1}, the decimal reduction number [DRN = $\log(N_0/N)$] can be considered as linearly related to Q with the decimal reduction energy [Q_D] varying between 44 ± 3.2 kJ kg^{-1} for 0.05 μs, 37 ± 2.5 kJ kg^{-1} for 0.1 μs and 32 ± 1.4 kJ kg^{-1} for 0.25–3 μs pulse width. For $Q = 0$–300 kJ kg^{-1}, the relation between Q and $\log(N_0/N)$ was of power law type with the threshold energy level $Q_0 = 9 \pm 2.6$ kJ kg^{-1} and the power coefficient 3.17 ± 0.21. For $Q = 65$ kJ kg^{-1} the increase of T_{INIT} by 6.6(±0.7) °C raises the DRN by one unit. The same effect increased the products' electrical resistance by 16(±1.4) Ω. For an overall treatment time of 1 μs, the DRN is linearly related to E, with threshold (E_0) and decimal reduction (E_D) electric field strength: $E_0 = 19 \pm 1.8$ and $E_D = 29.7 \pm 1.2$ kV cm^{-1}, respectively.

Keywords: *Salmonella enteritidis*; Pulsed electric field; Pasteurization; Processing parameters

1. Introduction

Interest in non-thermal processes for food preservation has been growing for more than three decades with increasing consumer demand for microbiologically safe and minimally processed food products. Among these processes, pulsed electric field process (PEF) represents one of the more promising technologies for the replacement of traditional thermal pasteurization (Barsotti & Cheftel, 1999; De Jong & Van Heesch, 1998; Heinz, Alvarez, Angersbach, & Knorr, 2002; Jeyamkondan, Jayas, & Holley, 1999; Sale & Hamilton, 1967; Van Loey, Verachtert, & Hendrickx, 2002; Vega-Mercado, Powers, Barbosa-Cánovas, & Swanson, 1995; Wouters, Alvarez, & Raso, 2001). The PEF process consists of the application of short time (2 μs to 1 ms) high voltage pulses (5–50 kV cm^{-1}) to liquid food placed between two electrodes, in order to inactivate microorganisms by mechanical effects on cell membrane with minimized ohmic heating. Microbial inactivation ranging between 2 and 6 decimal reductions was obtained at non-lethal temperatures for yeasts and many bacteria, according to microorganism type and growth stage (Castro, Barbosa-Canovas, & Swanson, 1993; Grahl & Märkl, 1996; Márquez, Mittal, & Griffiths, 1997; Qin, Pothakamury,

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Barbosa-Canovas, & Swanson, 1996; Wouters et al., 2001; Zhang, Chang, Barbosa-Canovas, & Swanson, 1994), physical properties of the treatment media (Dunn & Pearlman, 1987; Grahl, Sitzmann, & Märkl, 1992; Ho, Mittal, Cross, & Griffiths, 1995; Qin et al., 1995; Vega-Mercado et al., 1997; Zhang et al., 1994), PEF treatment conditions of electric field strength, treatment time, pulse wave shape, temperature (Bliska, De Bruin, & Krassowska, 2000; Castro et al., 1993; De Jong & Van Heesch, 1998; Grahl & Märkl, 1996; Heinz et al., 2002; Hülsheger, Potel, & Niemann, 1983; Jayaram, Castle, & Margaritis, 1992; Jeantet, Baron, Nau, Roignant, & Brulé, 1999; Jeantet et al., 2004; Knorr, Geulen, Grahl, & Sitzmann, 1994; Márquez et al., 1997; Peleg, 1995; Qin et al., 1996; Sale & Hamilton, 1967) and treatment chamber design (Qin et al., 1995; Zhang, Barbosa-Canovas, & Swanson, 1995; Lubicki & Jayaram, 1997; Jeyamkondan et al., 1999).

However, the scale up of PEF processing from these results remains often difficult, because of the heterogeneity of the procedures (batch or continuous mode), the incomplete characterization of the equipment and the absence of direct measurement of the key process factors (voltage, current, pulse width, temperature reached after treatment, etc.).

Considering this, a new concept of pulsed continuous electric field equipment has been developed. The spark gap switching technology used is designed to deliver square wave pulses with direct measurement and a great range of pulse duration, frequency and electric field strength (Jeantet et al., 2003; Jeantet et al., 2004). The aim of the present work is to study, with this equipment, the effect of PEF processing parameters (energy input, pulse width, initial product temperature, electrical resistance and electric field strength) on *Salmonella enteritidis* inactivation in a model solution.

2. Materials and methods

2.1. PEF equipment

The continuous PEF equipment developed (Fig. 1; Europulse, Cressensac, France) uses a novel pressurized spark gap switching technology (dry air) with high repetitive rate, connected to a pulse forming line consisting of a coaxial cable and lumped elements (Jeantet et al., 2003). This equipment, including a 2 kW high voltage power supply, charging capacitors and an interactive computer control developed with labview software, generates square waveform pulses. It is designed to allow a widely adjustable operating pulse width (50, 100, 250, 500, 1000, 2000 or 3000 ns), electric field strength (from 30 up to 80 kV cm^{-1}), pulse frequency (from 1 up to 815 Hz) and to produce a volumetric flow rate (from 1 up to 10 l h^{-1}).

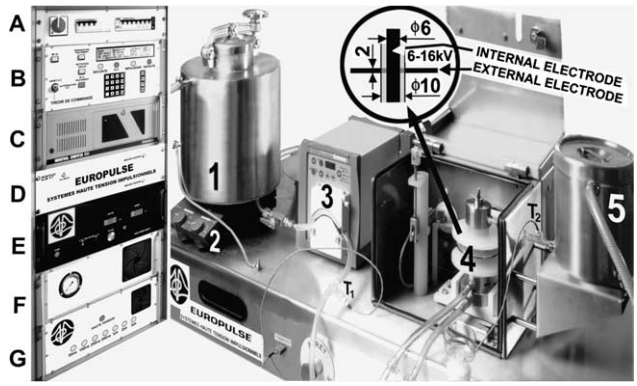

Fig. 1. Equipment for continuous PEF treatment of liquid products. *Control panel*: (A) power supply; (B) programming and control drawer; (C) computer; (D and E) high voltage monitor and power supply (50 kV, 2 kW); (F) spark gap switch (0–815 Hz); (G) high voltage energy storage (50 ns, 100 ns, 250 ns, 500 ns, 1 μs, 2 μs, 3 μs). *Hydraulic line*: (1) refrigerated supply tank (12 l); (2) magnetic stirrer; (3) peristaltic pump (0–25 l h^{-1}); (4) PEF treatment chamber; (5) tubular heat exchanger; T_1, T_2: thermocouples.

The coaxial continuous treatment chamber (insert in Fig. 1) is composed of two electrodes, a grounded central electrode of 6 mm diameter and a 2 mm thick external electrode. The electrodes are separated by a gap of 2 mm. To stabilize the liquid flow, the PEF treatment zone is preceded and followed by two 50 mm long coaxial zones of the same diameters as the inter electrode zone. The treatment chamber is equipped with a high voltage resistive and a current monitor for the direct measurement of applied voltage and current with a TDS 3012 digital oscilloscope (Tektronix, Beaverton, USA), having an acquisition frequency of 1.25 GHz and a storage capacity of 10,000 readings for each one of the two channels.

The hydraulic line includes a 12 l supply tank equipped with a cooling mantel and a variable speed peristaltic pump (0–25 l h^{-1}). The temperature rise due to ohmic heating is measured by two thermocouples placed immediately before and after the chamber. The outlet temperature after treatment is controlled by the computer: if it exceeds 50 °C the PEF treatment is automatically stopped. The cooling of the product immediately after treatment is provided by a tubular heat exchanger. A 20 kg full load digital balance controlled by the process computer measures the flow rate of the product.

2.2. Model solution

The model solution used in this study was composed of 28 mM sodium sulfate and 28 mM glucose (Panreac, Barcelona, Spain), corresponding to the aqueous phase of egg white in terms of ionic strength and glucose concentration. Its conductivity σ (S m^{-1}) as a function of the temperature was measured with a 145A+