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Metal release in a stainless steel pulsed electric field (PEF) system Part II. The treatment of orange juice; related to legislation and treatment chamber lifetime

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Abstract

In the last decennia, there is an increasing interest in pulsed electric field (PEF) treatment. The product is often treated in a continuous flow treatment chamber with stainless steel electrodes and exposed to short pulsed electric fields, typically 2–4 kV·mm^{-1} during 1–10 μs. Due to direct contact of the treatment chamber electrodes with the food product, the main elements of these stainless steel electrodes are able to dissolve in the treated product. The magnitude of the material transfer depends on many factors such as current magnitude, pulse duration, pulse shape, and product constitution. In this contribution, the effect of metal dissolving during a monopolar pulse shape, generated by a pulse forming network, is investigated. Experiments are carried out with single and repeated PEF treatments in orange juice. These experiments showed that, due to PEF treatment, dissolved metals are present in the juice. The four main elements of stainless steel, iron, chromium, nickel, and manganese, have been considered in particular. The metal concentrations found do not exceed the legislation values for fruit juices and the EU Drinking Water Directive [EU Drinking Water Directive, http://www.europe.eu.int/.] for human consumption. From the experiments, a relationship between dissolved metals in orange juice and the transferred charge is derived. In addition, a lifetime prediction of the treatment chamber caused by release of metals has been made.

Keywords: PEF; Orange juice; Metal release; Legislation; Treatment chamber lifetime

Industrial relevance: This paper investigated the metal release in a stainless steel pulsed electric field (PEF) system by considering the effect on a real food product, in this case orange juice. This issue and the description about pulse shapes in Part I are of great importance for the commercialisation of the PEF technology. A relationship is determined between the dissolved metals in orange juice and the transferred charge. This parameter can be used during the development of larger PEF treatment systems for orange juice. For the described treatment system, a treatment chamber lifetime prediction is given that is based on the released metal concentrations. The metal concentrations are also compared to the Dutch and European legislation rules.

1. Introduction

In the food industry, pulsed electric field (PEF) treatment has gained increasing interest, which is mainly caused by some attractive advantages in relation to conventional thermal treatments. Especially for the treatment of raw products, like fresh squeezed oranges. For these types of products, PEF can reduce or even avoid the loss of flavour and freshness appearance of the product. During PEF, the product is exposed to an electric field of typical 2–4 kV·mm^{-1} during 1–10 μs. The application of external high electric fields to biological cells will cause irreversible pore formation into the microorganisms' membrane, which finally cause cell death (Wouters & Smelt, 1997). During the treatment, the electrodes are in direct contact with the food product. In the interfacial region between electrode and

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liquid, in order to preserve the charge conservation principle, electrochemical reactions will start. Several research groups and companies all over the world have great interest in PEF treatment, so information about metal release in real food products, caused by these reactions, are of great importance. Especially in relationship with the applied current, this directly depends on important parameters like treatment chamber geometry, product conductivity, and PEF treatment. Also an important question: Is it necessary to equip the PEF treatment system with auxiliary circuits to get zero net charge, described by Bushnell, Clark, Dunn, and Lloyds (1995), to satisfy food legislation and regulation rules?

In Part I of this contribution "Metal release in a stainless steel pulsed electric field (PEF) systems—Effect of different pulse shapes; theory and experimental method", a comparison is made between the metal release of three different pulse shapes generated by three slightly different PFN topologies. The theory and the experimental method are also discussed. The topology equipped with the output transformer, which gives the lowest dissolved metal concentrations, is used to investigate the metal release in relation with a real food product. In this contribution, Part II, three types of (PEF) experiments have been carried out to investigate the metal release in a real food product, in this case orange juice.

1. Orange juice is exposed once to a realistic PEF treatment
2. Orange juice is exposed to the same PEF treatment but by repeatedly circulating
3. The same repeatedly circulating treatment as mentioned under (2) but now without PEF treatment

The experiments have been carried out with a stainless steel PEF treatment chamber, which is described by Van den Bosch, Morshuis, and Smit (2001). During all experiments, samples were taken before, during, and after the experiment. From these samples, the metal concentrations of iron, nickel, chromium, and manganese were determined. The concentrations are compared with the legislation rules and are used to make a treatment chamber lifetime expectation.

2. Methodology and results a summary of Part I

2.1. Treatment system

There are many different pulsed power topologies that can be used to generate pulsed high voltages. For large industrial processing plants, which are treating usually one product, simple monopolar pulse generators with a so-called pulse forming network (PFN) are preferred because of their simplicity. Such pulse generators must be equipped with a parallel output inductor or an output transformer to keep the dissolved metal concentrations as low as possible. The pulse generator, which is shown in Fig. 1, gives the lowest dissolved concentrations and is therefore used for the experiments described in this contribution.

The PFN, which consists of six stages of 5 nF and 1.3 μH ($n=6$), has a characteristic impedance Z_C and pulse duration t_p of 16 Ω and ~1 μs, respectively. The PFN capacitors are charged prior to each pulse and a self-diminishing pulse appears after connecting it to the load. A detailed description of this pulse generator is given by Roodenburg, Morren, De Haan, Prins, and Creyghton (2002) and a comparison of different pulse generation techniques for PEF is described by De Haan and Willcock (2002).

The output of transformer T is directly coupled with the stainless steel AISI 316L co-field treatment chamber of Fig. 2, which is based on the so-called OSU geometry from Yin, Zhang, and Sastry (1997). A detailed analysis of this treatment chamber is given by Van den Bosch et al. (2002).

2.2. Metal release and charge relationship

Via the transferred charge per pulse, the total treatment time and the repetition rate it is possible to determine the total transferred charge at the electrode. This total amount of

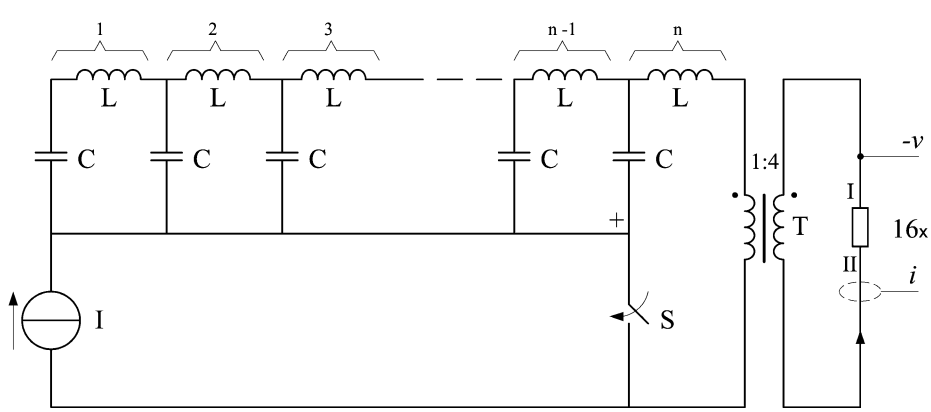

Fig. 1. Pulse generator circuit used for the metal release experiments.