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Pulsed Electric Field food treatment - scale up from lab to industrial scale

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Abstract

By pulsed electric field (PEF) application a permeabilization of plant, animal and microbial cells is achieved. The work has focused on identification of suitable processing and equipment parameters for a scale-up of PEF food processing as well as equipment design. Following the principles of process design, the principle action and the impact of processing parameters were identified. By modeling of inactivation kinetics and intensity distributions design guidelines for pulse generators and treatment chambers have been derived. Different treatment chamber configurations have been evaluated with regard to field homogeneity, flow pattern as well as cleanability. Equipment with an average power level of 5, 30 and 80 kW was developed, allowing a treatment capacity of up to 10.000 l/h.
The techniques scalability to an industrial level was shown. Along with application examples, the equipment design will be discussed.

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Keywords: Pulsed Electric Fields, Cell disintegration, Preservation, Electroporation

1. Introduction

Since the first reports of pulsed electric field (PEF) impact on plant, animal and microbial cells in the 1960s numerous applications in food and bio-engineering have been investigated [1]. To allow a successful commercial application industry ready, turn-key equipment as well as knowledge on the technique´s scalability is required [2]. PEF systems are a setup of a suitable pulse generator to provide electric energy and a treatment chamber. Pulse peak voltage and current, pulse width and repetition and the average power level are the most important design parameters for the pulse generator. The transfer from lab to industrial scale requires a scale-up of average power from a few kW up to > 100 kW systems. Within the treatment chamber, the electric energy is transferred to the treated media. Electrode configuration and area, gap as well as the flow pattern are considered as major design parameters.

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Electrode erosion has been reported for stainless steel electrodes [3], requiring the identification of suitable alternatives for commercial applications.

This work has focused on identification of suitable processing and equipment parameters for a scale-up of PEF food processing as well as equipment and treatment chamber design. Based on the identification of important processing parameters scale-up guidelines have been derived to design pulse generators as well as treatment chambers for liquid media treatment.

Fig. 1. 30 kW PEF system (left), treatment chamber setup (right)

2. Materials and Methods

Following the principles of process design, the study was performed by identification of principle of action, characterization of the impact of processing parameters, modelling of inactivation kinetics and intensity distributions and the design of pulse generators and treatment chambers. The impact of pulsed electric fields on disintegration of plant cells as well as inactivation of pathogenic and spoilage organisms in fruit juices and smoothies as well as milk and whey protein concentrates has been evaluated. An electric field strength of 2 to 30 kV/cm, an energy input of 5 to 250 kJ/kg and a treatment temperature of 10 to 60°C were applied. After treatment, survivors have been enumerated. To evaluate the effect of process capacity, PEF equipment with a capacity of 20 l/h (3 kW), 200 (5 kW) l/h and 2.000 l/h (30 kW) (Figure 1) has been used. The pulse generators are based on a solid state typology, making use of a pulse transformer. Different treatment chamber configurations (co-linear, co-axial, in-axial, concentric rift, field concentration chamber, see Figure 2) and electrode materials (stainless steel (1.4301; 1.4404), titanium, platinum) have been evaluated with regard to electrode erosion, field homogeneity, flow pattern as well as cleanability.

3. Results and Discussion

To allow selection of suitable processing parameters, the impact of PEF treatment parameters on plant and microbial cells was evaluated. Electric field strength, specific energy input and temperature were identified as major processing parameters. Whereas the field strength showed a threshold effect, the specific energy input could be applied as a dose parameter. Dependent on type of application, the specific energy input required was in a range of 5 - 10 kJ/kg for permeabilization of plant tissue and 50 - 200 kJ/kg for preservation of liquid media. Successful inactivation of 5 to 7 log cycles of microbial cells has been shown in tap water, fruit juices,

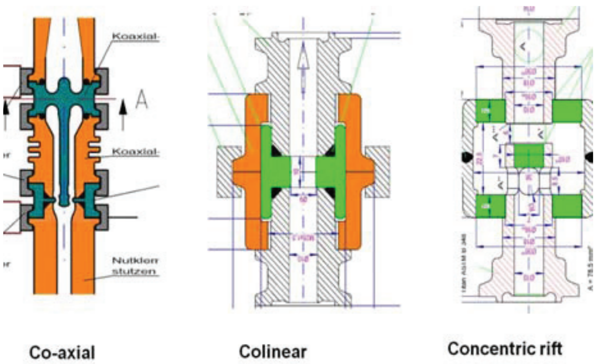

Fig. 2.: Treatment chamber configurations

smoothies, milk and cream, beer as well as vitamin solutions or nutrient media. In addition also particulate media such as fruit preparations or sauces can be preserved. As an example the inactivation of four microbial strains in fruit juice is shown in Figure 3. As an example for a heat sensitive product, a shelf life study for a freshly squeezed orange juice was performed. By sensorial analysis the maximum

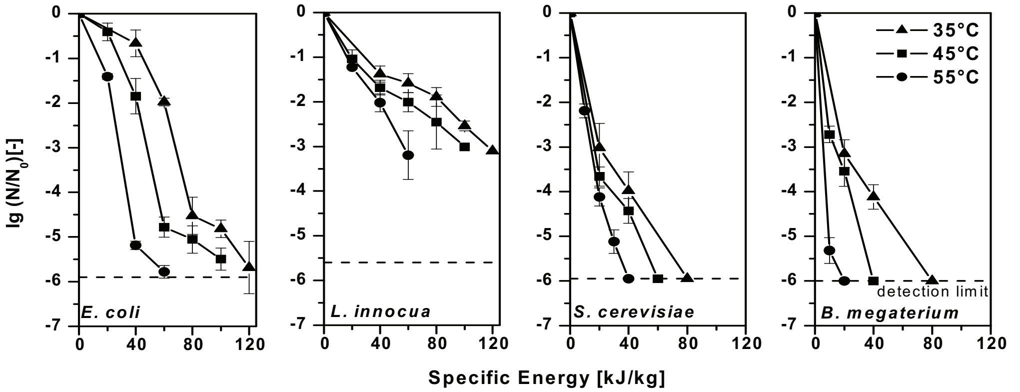

Fig. 3. Inactivation of E. coli, Listeria innocua, Saccharomyces cerevisae and Bacillus megaterium in a fruit juice after PEF-treatment at a field strength of 20 kV/cm dependent on initial temperature and electric energy input

allowable treatment intensity – where no taste and flavour changes where detected by a panel of five persons – was set. The juice has shown a detectable cook flavour in comparison to freshly squeezed juice, when the maximum temperature after treatment exceeded a value of 61°C. At a start temperature of 40°C, this level was reached at an energy input of 120 kJ/kg and a field strength of 20 kV/cm. A treatment at this settings resulted in a 5 log reduction of E. coli 35218, while maintaining fresh, natural taste. Making use of a combined heat and PEF treatment the energy input required was reduced and a superior juice quality achieved. After a treatment at these settings, the shelf life was increased from 7 days (untreated) to more than 21 days (see Figure 4).

Amongst the chamber con¬figurations a co-linear design with mixing inlay resulted in optimum treatment efficiency. The static mixer enforces the product flow through an area with high field strength and field homo¬geneity. Titanium electrodes have shown a superior resis¬tance against corrosion in com¬parison to stainless steel electrodes. The titanium content was below the detection limit (50 ng/l) in the products tested.

Equipment with different average power and treatment capacity was developed to evaluate the techniques scalability. The solid state typology has shown to be suitable for a reliable, long term application for liquid media

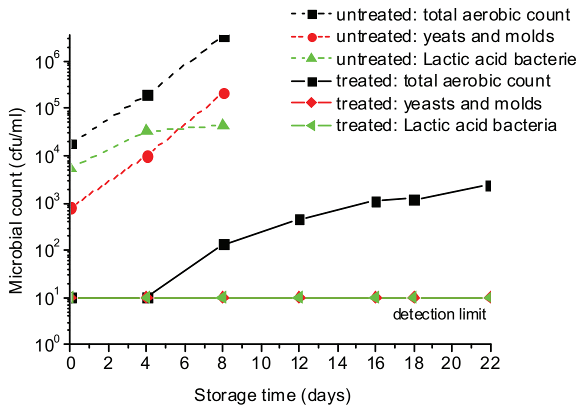

Fig. 4. Microbial load in freshly squeezed orange juice without and with (20 kV/cm, 40°C, 120 kJ/kg) PEF treatment

treatment. The comparison of different treatment capacities showed that the inactivation level was not dependent on the flow rate in a range from 20 to 2.000 l/h, when energy input and flow pattern were kept constant. A successful transfer of processing conditions from lab to industrial scale was achieved. At present the treatment capacity is extended further, based on 80 kW modules systems with an average power of up 240 kW are realized, allowing a treatment capacity of 10.000 l/h for microbial decontamination. Due to the development the technique is available for industrial scale processing. The total treatment costs can be estimated in a range of 1 – 2 €/t of material to be treated for cell disintegration and 0.01 to 0.02 €/l of liquid media preservation.

4. Conclusion

The techniques scalability to an industrial level was shown. The applicability of electric field strength, specific energy input as well as treatment temperature process design parameters was confirmed. Equipment for an industrial application has been developed.

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