



Theme: Food Security

Research paper

Simulation Study of a Helical Treatment Chamber for PEF Pasteurization

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Highlights

- Non-uniform distribution of electric field is a common problem inside the treatment chambers for PEF treatment
- Laminar flow inside the treatment chamber is a reason for treatment inhomogeneity in the treatment chambers
- Helical shape provides the tabular flow of the liquid and so uniform electric field distribution to the whole sample

About Authors

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Abstract

Pulsed electric field (PEF) is a developing non-thermal way for the treatment of fruit juices. Due to the low consumption of energy in this treatment, the temperature of the sample liquid remains low. So, it helps to preserve the taste as well as the nutritional value of the liquid food. However, non-uniform distribution of electric field is a common problem inside the treatment chambers. The laminar flow inside the treatment chamber is a reason for treatment inhomogeneity in the chambers. The helical shape is a motivation due to its favorable features, including the tabular flow of the liquid inside the chamber. Numerical simulation is a way to analyze the distribution of the electric field before designing any treatment chamber. The simulation results indicate a homogenous electric field strength in the helical treatment chamber. This study provides new insights into industrial-scale set-up by using multiple helical chambers in a continuous flow PEF pasteurization.

1. Introduction

PEF treatment has been concentrated as a non-thermal fruit juice protection strategy for pasteurization (Roobab et al., 2018). A large number of researchers have confirmed that PEF processing is able to deactivate microorganisms deprived of varying the freshness of treated liquid foods (McAuley et al., 2016; Ramaswamy and Ramachandran, 2016). In PEF pasteurization, a food sample is placed in an insulated treatment zone surrounded by electrodes, connected to a high voltage pulse generator. High voltage pulses develop an electric field to the sample placed in the treatment chamber to carry out membrane electroporation (Mohamed and Eissa, 2012). A properly designed treatment chamber is pivotal to bring about more powerful and uniform PEF to either kill or weaken the microorganisms in the juices (El-Hag et al., 2006, Ohshima et al., 2016). One of the methods for upgrading treatment uniformity of continuous PEF systems is to change the shape of the treatment chamber, which can bring about a supplementary uniformly distributed electric field strength and/or also upgrade the flow patterns of the treated substance.

Most of the continuous PEF treatments have used the co-linear shape of the electrodes (Jaeger et al., 2009). However, this configuration of electrodes has nonuniform distribution of electric field compared to the coaxial or parallel configuration of the electrode (Meneses et al., 2011). The current design of the helical treatment chamber with coaxial electrodes has a tendency to capture the industry in pasteurization, as it can be fabricated simply and provides well-defined distribution of electric fields. More importantly, it minimizes or eliminates the peak value of an electric field in the treat-

ment region. Since its electrodes have a very large cross-sectional area producing a large amount of current flow through the treatment chamber (Knoerzer et al., 2012).

The flow rate is an important interdependent parameter in the continuous PEF processing and also plays an unavoidable role in homogeneity of the electric field. Jaeger et al. (2009) and Meneses et al. (2011) studied the shape of the treatment zone and the flow rate of the liquid food and found that the laminar flow is a reason for treatment inhomogeneity in most of the treatment chambers. Turbulent flow is likely to be produced with a higher flow rate. The helical chamber was also the motivation owing to the flow geometry, because swirl of the helical treatment zone produces a turbulent flow of sample irrespective of its viscosity (Islek, 2004). Furthermore, it provides an enhanced exposure time. Thus, the combination of coaxial electrodes with helical treatment zone can provide a uniform electric field to the entire liquid sample.

The principal reason for the present investigation is the assessment of the capability of the helical geometry for the enhancement of the electric field distribution to the whole treated sample.

2. Materials and Methods

2.1 Treatment Chamber

The helical treatment chamber was composed of dual hollow cylindrical electrodes, made of hollow Stainless Steel. The inner and outer electrodes have a diameter of 4.5 and 5.5 cm respectively. The inner electrode was connected to a high voltage power supply, and the ground terminal of the supply was attached to the outer electrode. The helical shape was fabricated by a Pyrex glass tube with 8 mm inner diameter and 1mm wall thickness as shown in Figure 1. The helical treatment zone was inserted between these two electrodes and was helpful to the flow of liquid sample through the chamber, as shown in Figure 2. The 8 mm inner diameter of the treatment zone allowed the fruit juice to flow easily. Hence, the total distance between the two electrodes was 1 cm. Fig. 1 illustrates the designed helical treatment zone with its cross-sectional view, and Fig. 2 shows the complete helical treatment chamber.

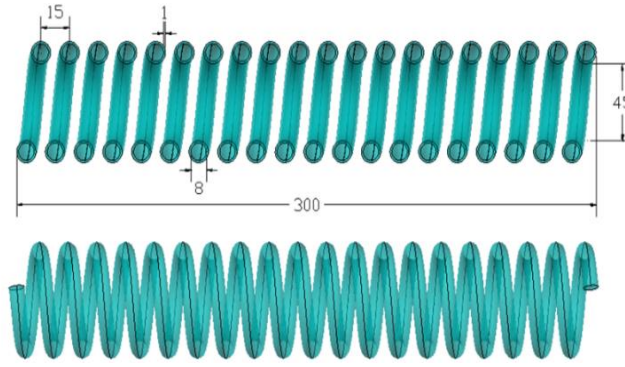


Figure 1: Helical treatment zone (all dimensions are in mm)

The applied voltage was calculated for electric field strengths of 30 kV/cm in the treatment region. The following equation was used to calculate the maximum value of the applied pulsating voltage:

$$V = E * r \ln(R_o/R_i) \quad (1)$$

Where ‘E’ is the electric field (kV/cm) at location ‘r’ (cm) such that $R_i \leq r \leq R_o$. ‘R_i’ and ‘R_o’ are the radii of the internal and external electrodes, respectively. If we put E = 30kV/cm, r = 5cm, R_o = 5.5cm and R_i = 4.5cm in equation 1 so we can calculate the maximum required voltage of 30kV for electric field strength of 30kV/cm.

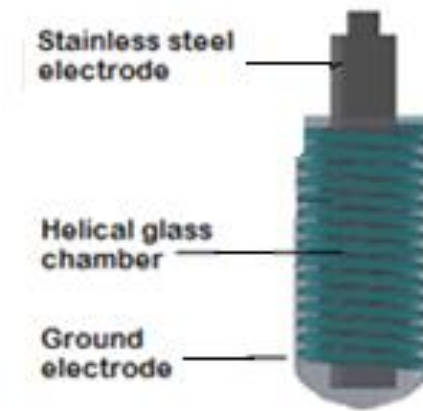


Figure 2: A Helical treatment chamber

2.2 Computational Methods

The COMSOL Multiphysics™ was used for simulating the electric field distribution in the helical treatment chamber. The helical treatment chamber was designed in COMSOL as shown in Figure 3. Most of the mesh was automatically produced and improved manually at the curved part of the treatment zone. All this simulation was done by a desktop computer with an operating system Windows 10, Intel® Core™ i5-2400 CPU @ 3.1 GHz and 16 GB RAM. It took ~10 minutes to com-

plete the entire computation.

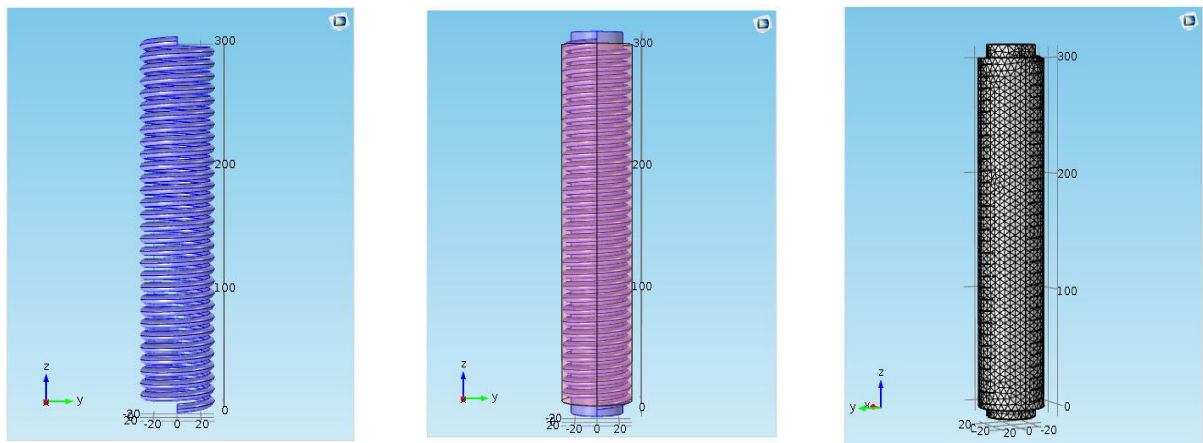


Figure 3 Helical Treatment Chamber geometry in COMSOL

A simulation study was done by using static conditions with a supposition that there were no electromagnetic forces, so the equation among the vector electric field ‘E’ in (V/m) and the scalar electric potential ‘V’ in (V) can be described as:

$$E = -\nabla V \quad (2)$$

Where ∇ is the gradient (spatial/vector differential) operator.

This governing equation is capable of defining appropriately the electrostatic model for simulating the electric field in COMSOL Multiphysics.

In the electrostatics mode, the electric potential identifies the maximum value of the applied voltage at the internal electrode, and zero at the external electrode in the coaxial configuration of electrodes.

Inner electrode $V = V_{in}$; With V_{in} is the maximum pulsating applied voltage.

Outer electrode $V = 0$

The boundaries of the inlet, outlet, and insulators were set to be electrically insulated:

$$\mathbf{n} \cdot \mathbf{J} = 0$$

where ‘n’ is the unit vector and normal to the direction of the boundary.

3. Results and Discussion

Fig. 4 demonstrates the expected uniform electric field distribution in the proposed helical treatment zone with coaxial electrodes. with this configuration, the electric field is distributed in a descendant order from the inner electrode in the direction of the outer electrode. The strength of this electric field is greater in the locality of the inner electrode connected to high voltage than the areas connected to the outer grounded electrodes as noted through calculations.

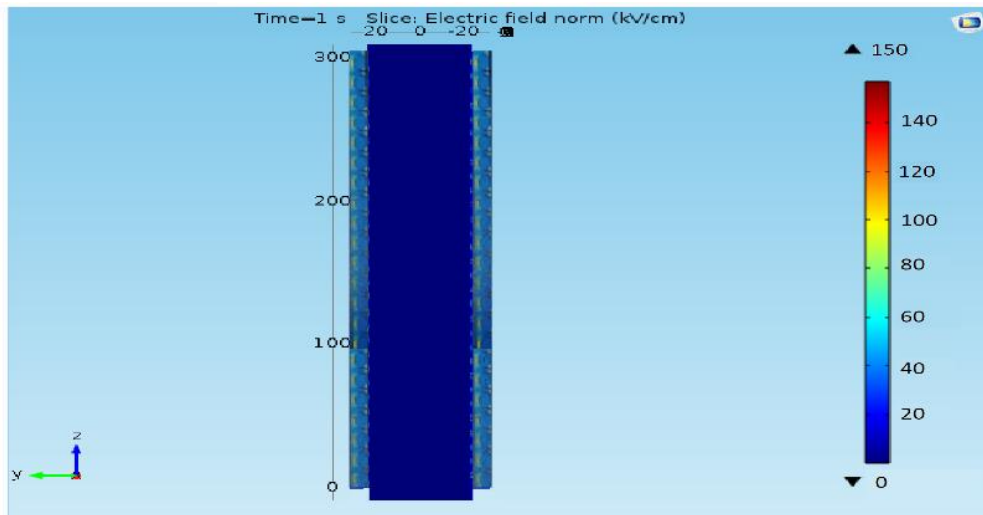


Figure 4: sketch of electric field strength uniformity of the helix treatment chamber

Small variances in the electric field strength within the treatment zones can be recovered due to the turbulent flow of the whole liquid sample. Since there's no presence of edges in this design so it provides a uniform distribution of electric field strength in the treatment zone as compared with other coaxial treatment chambers developed by Pizzichemi, 2007. Moreover, as the treatment time is calculated by dividing the volume on the flow rate, because of this, by increasing the length of the treatment chamber, the volume is increased, the exposure time will also increase, which results in improved log reduction.

4. Conclusion

Designing a treatment chamber in PEF processing is a critical task for homogeneous treatment. Prior to the development of a new treatment chamber, this simulation work helps to get a decent estimation of the distribution if the electric fields. The Helical geometry of the treatment chamber shows significant improvements on the basis of simulation results. The current study shows that the present scheme of the insulator and electrode can apply uniformly to the whole treated sample. Additional effort will target the confirmation of this numerical simulation outcome with the optimal design of the treatment chamber with the intention of attaining more uniform treatment and minimum consumption of electrical power.

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References

- EL-HAG, A. H., JAYARAM, S. H. & GRIFFITHS, M. W. 2006. Inactivation of naturally grown microorganisms in orange juice using pulsed electric fields. *IEEE transactions on plasma science*, 34, 1412-1415.
- ISLEK, A. A. 2004. *The impact of swirl in turbulent pipe flow*. Georgia Institute of Technology.
- JAEGER, H., MENESES, N. & KNORR, D. 2009. Impact of PEF treatment inhomogeneity such as electric field distribution, flow characteristics and temperature effects on the inactivation of *E. coli* and milk alkaline phosphatase. *Innovative food science & emerging technologies*, 10, 470-480.
- KNOERZER, K., BAUMANN, P. & BUCKOW, R. 2012. An iterative modelling approach for improving the performance of a pulsed electric field (PEF) treatment chamber. *Computers & Chemical Engineering*, 37, 48-63.
- MENESES, N., JAEGER, H., MORITZ, J. & KNORR, D. 2011. Impact of insulator shape, flow rate and electrical parameters on inactivation of *E. coli* using a continuous co-linear PEF system. *Innovative food science & emerging technologies*, 12, 6-12.
- MOHAMED, M. E. & EISSA, A. H. A. 2012. Pulsed electric fields for food processing technology. *Structure and function of food engineering*. InTech.
- OHSHIMA, T., TANINO, T., KAMEDA, T. & HARASHIMA, H. 2016. Engineering of operation condition in milk pasteurization with PEF treatment. *Food Control*, 68, 297-302.
- PIZZICHEMI, M. 2007. Application of pulsed electric fields to food treatment. *Nuclear Physics B-Proceedings Supplements*, 172, 314-316.
- ROOBAB, U., AADIL, R. M., MADNI, G. M. & BEKHIT, A. E. D. 2018. The Impact of Nonthermal Technologies on the Microbiological Quality of Juices: A Review. *Comprehensive Reviews in Food Science and Food Safety*, 17, 437-457.

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