Analysis of pulsed electric field pre-treatment for beet juice extraction: Evaluation of treatment chambers configuration effects

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Abstract : The major challenge today for the application of Pulsed Electric Field (PEF) in the industry has interest to increase the production capacity and improve the quality of food products. PEF pre-treatment is a multifactorial process. In addition to the electric field intensity, pulses number and the capacitor value, the configuration of the treatment chamber now presents a significant parameter in this process. The main objective of this work is to show that it is possible to give more juice by cylindrical treatment chamber with a good quality of betanine. For this purpose, cylindrical and square parallelipedic treatment chambers (TC) are compared and their effect is studied with variation of electric field, number of pulses and capacitor value at frequency of 1Hz. The results show that the cylindrical treatment chamber showed higher beet juice yield with all studied parameters. The quality of extracted juice estimated in terms of absorbance at 530 nm wavelength were determined for each sample and results show that using a cylindrical treatment chamber configuration in PFE technology gives a good juice quality compared with the square parallelipedic treatment chamber. The energy consumption during PEF treatment is reduced in the cylindrical treatment chamber due to the low values of the electric field, pulses number and capacitor value compared with square parallelipedic treatment chamber.

Keywords: Treatment chmaber, Pulsed electrical field (PEF), beet juice, food, absorbance, betanine.

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1 Introduction

Pulsed electric field (PEF) applications can be utilized to achieve disintegration of biological tissues or microbes (Donsì et al., 2010). Various applications have been identified such as improvement of mass transfer during extraction or drying as well as gentle food preservation. This process can be considered as a potential alternative to traditional thermal treatment for food with the advantages of minimising sensory, and nutritional damage, thus providing fresh-like products (Alirezalu et al., 2019; Korma et al., 2016; Lamanauskas et al., 2015). The technology involves the application of short pulses (microseconds pulse duration) of high voltage to food sample placed between two electrodes. The applied pulse energy destroys the cell membrane, resulting in the creation of pores called the phenomenon of electroporation with minimal heating of the food (Singh et al., 2012).

The applied electric field creates a critical trans-membrane potential, the electrically charged lipid bilayer in the microorganisms can no more sustain the electromechanical shear forces (Warshaviak et al., 2011).

Consequentially, ruptures leading to reversible damage of the cells are observed assuming appropriate

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pulse width and frequency. The critical electric field required to cause reversible damage to the cells depends on the physical and chemical characteristics of the cells as well as the medium in which it is suspended (Korohoda et al., 2013; Silve et al., 2016).

PEF is particularly well suited to processing fruit and vegetable juices because the enlargement of the cell pores makes juice.

PEF processing has been successfully used for variety of liquids and pumpable food products such as orange and cranberry juices, (Buckow et al., 2013) and apple juice and cider (Dziadek et al., 2019) without any loss of their natural characteristics. It has also been successfully used in enhancing juice extraction from blueberry, sugar beet, and microalgae (Bobinaitė et al., 2015; Loginova et al., 2012; Mauricio et al., 2013).

The pulsed electric field method, applied to the food field, consists in subjecting the food to electric fields of very high intensity (5 to 55 kV / cm), repeatedly (pulsed), for very short periods of time (from order of the microsecond), in order to treat the food product they contain. The food product is placed in the treatment chamber, where two electrodes are connected together with a nonconductive material to avoid electrical flow from one to the other (Mahalleh et al., 2019; Puértolas et al., 2013; Yashwant et al., 2015).

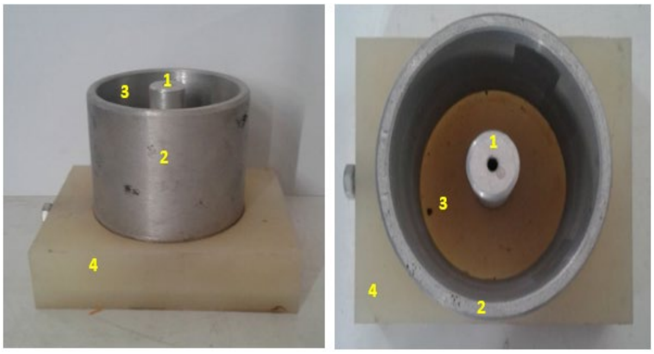
Nowadays, despite the fact that the treatment chambers currently used give good performances, a good electric field distribution in the treatment chamber remains a major challenge for the PEF technology in order to better treat the food. The main objective of this work is to show that it is possible to give more juice by cylindrical treatment chamber with a good quality of betanine.

2 Materials and methods

Beets were crushed with a household robot to obtain a homogeneous leg. The sample was held in a closed container to prevent evaporation before use. A beet paw sample of mass 80 g was used for each experiment. After PEF treatment, an extraction step was achieved using an extraction chamber and a hydraulic pressing machine (Mega, 15 tons).

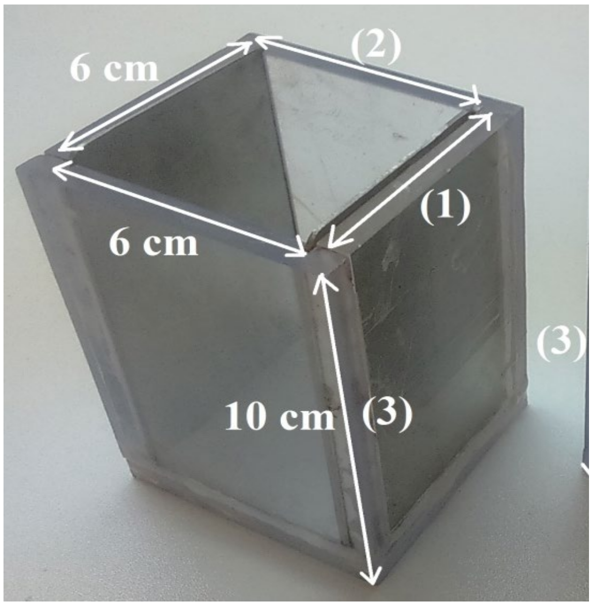
The PEF treated extracted juice was then analyzed by measuring both its mass using an electronic balance of 0.1 mg precision and the betanine amount using a spectrophotometer (Optizen 200 plus) for λ= 530 nm.

All experiments were carried out on a laboratory experimental bench at Djillali Liabes University of Sidi Bel Abbes, Algeria while maintaining following factors at constant values: pulse repetition frequency f = 1 Hz, extraction pressure P = 50 kg/cm^2, total pressing duration t = 300 s and the inter-electrodes gap d= 60 mm (Bellebna et al., 2014; Luengo et al., 2013).



1. Internal electrode, 2. External electrode, 3. Gap between the electrodes, 4. The basis of the treatment chamber

Figure 1 The cylindrical treatment chamber configuration

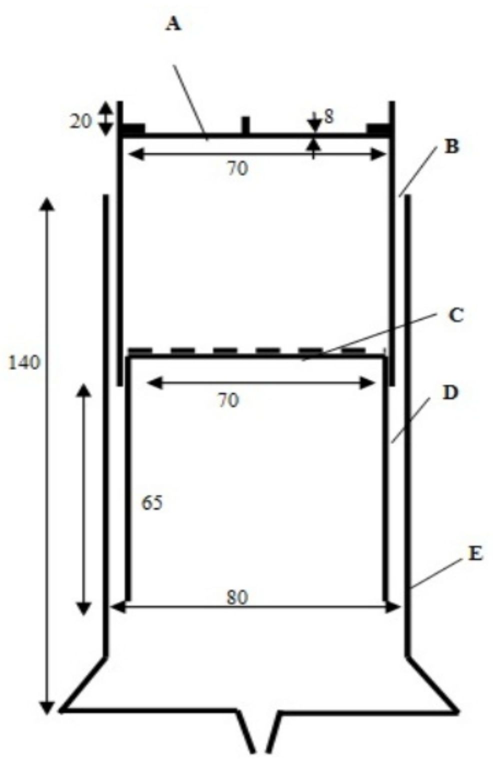


1: Electrode; 2: Insulating; 3: Plexiglas

Figure 2 The square parallelipedic treatment chamber

A cylindrical treatment chamber configuration was used in this study and compared with a parallel treatment chamber configuration. The cylindrical treatment chamber configuration consists of two concentric cylindrical electrodes, an external electrode connected to the ground of 8 cm and an internal electrode of 2 cm diameter connected to the high voltage and a gap between the electrodes of 6 cm (Figure 1). The second configuration is square parallelipedic treatment chamber made of Plexiglas, of dimensions 6x6x10 cm^3, in which are placed vertical stainless steel electrodes, were used in this work (Figure 2).

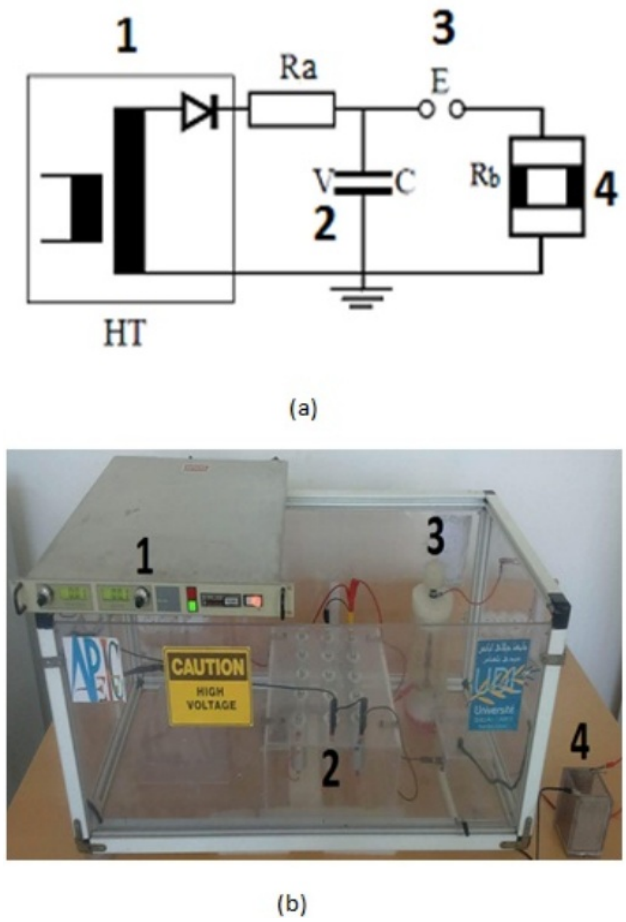
The chamber for extraction consisted of an insulated cylinder made of plastic (Teflon, PTFE) of length 140 mm and diameter 70 mm (Figure 3), a cylindrical plunger and a disc base of a same diameter 70 mm having a rigid structure for juice pressing operation, both made with stainless steel. Extracted juice was filtered through a stainless steel sieve placed on the top of the perforated plunger. Juice extracted during pressing was collected in a plastic collector placed under this chamber. The volume of the treatment chamber was 192.3 mL. For all experiments, the same treatment chamber was used for both pressing step.



A-Stainless Steel disk, B – Teflon cylinder, C – Stainless steel sieve, D -Perforated stainless steel plunger, E- Plastic container for the collection of extracted juice (Bellebna et al., 2017).

Figure 3 Schematic description of the chamber for extraction step (All dimensions are in mm)

The experimental setup used in the present work is composed of several components, comprising a high DC voltage source, an energy storage capacitor, a spark gap switch, and a treatment chamber (Figure 4). A DC high voltage supply (Spellman 40 kV, 9 mA) charges the bank of capacitors until producing the spark gap's breakdown, causing an abrupt voltage (shock) applied to the load (treatment chamber where the sample is disposed). The storage element is composed of three sets of five series capacitors (2 μf, 3 kV), with the possibility to reach a maximum voltage of 15 kV and a total capacitance of 1.2 μF (Figure 4).



a) Descriptive schematic of the setup; b) The photography of the setup; 1- HV DC power supply, 2-Set of capacitors, 3- Spark gap switch, 4-Treatment chamber (Bellebna et al., 2017).

Figure 4 The pulse generator

The three following factors were considered in this work: the applied voltage V (kV), the number of pulses (n) and the capacitor value C (μF).

Moreover, the mass of extracted juice m (g), the amount of betanine expressed in terms of Abs were considered significant to be considered as the response of the model. Absorbance (Abs) is the measurement of the amount of light absorbed by a given material for a determined wavelength using a spectrophotometer which is proportional to the coloration rate. Higher is the absorbance greater is the concentration of betanine substance.

The energy consumed during pulsed electric field treatment was another response to be considered in this study (Qin et al., 2014) which is measured and calculated by:

$W = ½ n C V^2$

n: Pulses number

C: Capacitor value (µF)

V: Applied voltage (kV)

In addition to the extraction efficiency, the comparison between the two models should be performed in terms of energy consumption, by the evaluation of the energy saving using the following relation:

$$W_{Savig} = \frac{W_{TC1} - W_{TC2}}{W_{TC1}}$$

W_{TC1}: Energy of square parallelipedic treatment chamber,

W_{TC2}: Energy of cylindrical treatment chamber.

3 Results and discussions

For all the experiments carried out in this section, for each configuration model, one factor was varied while the two other factors were kept at constant values.

Thus, Figures 5-7 represent the variation of the PEF treatment efficiency, in terms of extracted juice mass (M) according to the voltage V, the pulses number n and the capacitor value C respectively.

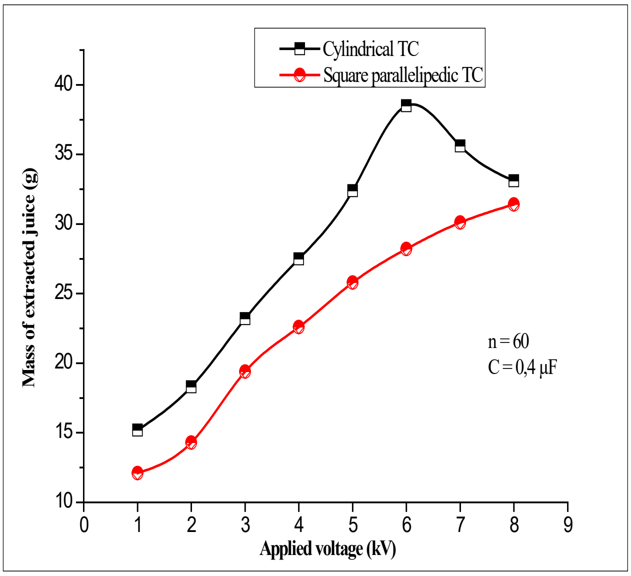


Figure 5 Mass of beet juice extracted for both treatment chambers configuration according to applied voltage (n = 60, C = 0.4 µF)

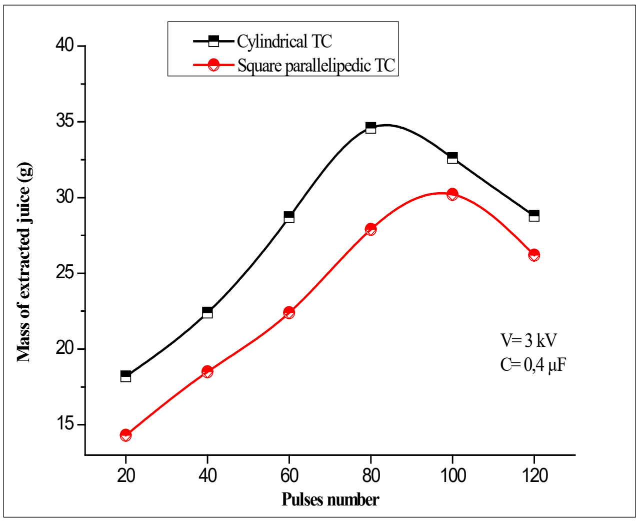


Figure 6 Mass of beet juice extracted for both treatment chambers configuration according to pulses number (V = 3 kV, C = 0.4 µF)

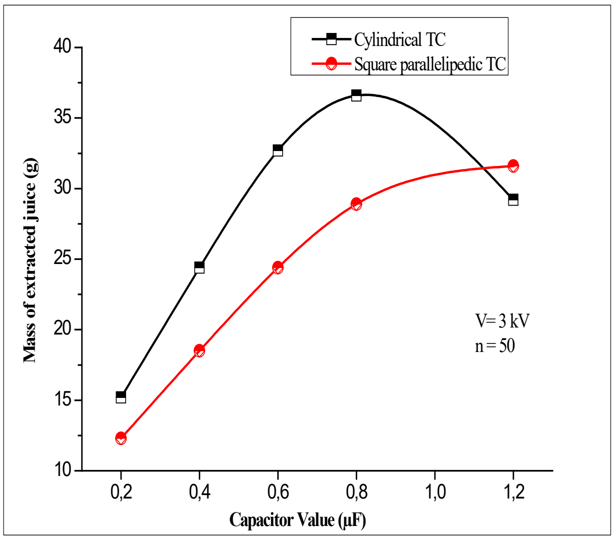


Figure 7 Mass of beet juice extracted for both treatment chambers configuration according to capacitor value (V = 3 kV, n = 50)

In the same way, the variation of the PEF treatment efficiency in terms of extracted Absorbance according to the voltage V, the pulses number n and the capacitor value C respectively are presented in Figures 8-10.

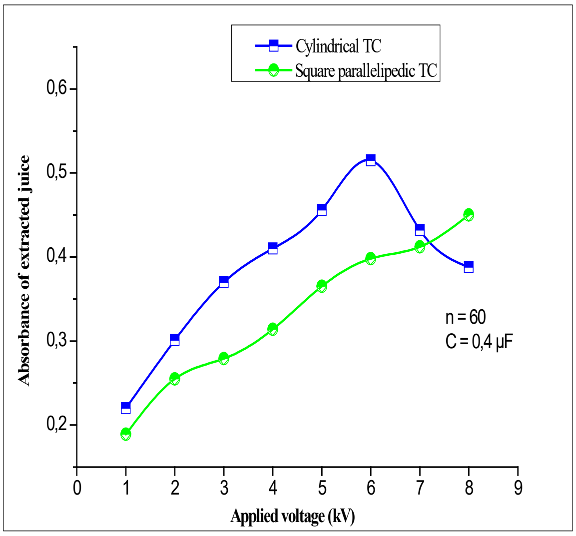


Figure 8 Absorbance of juice extracted for both treatment chambers configuration according to applied voltage (n = 60, C = 0.4 µF)

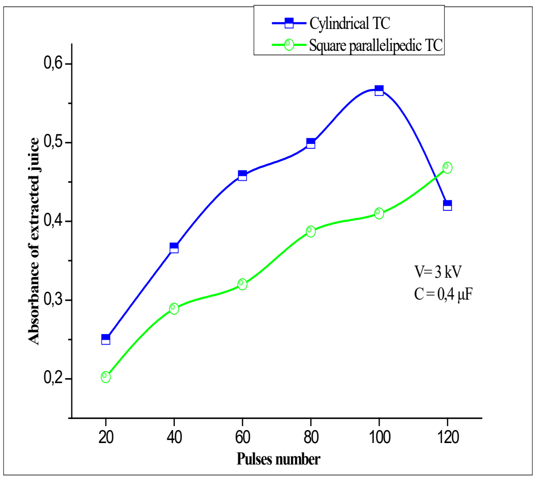


Figure 9 Absorbance of juice extracted for both treatment chambers configuration according to pulses number (V = 3 kV, C = 0.4 µF)

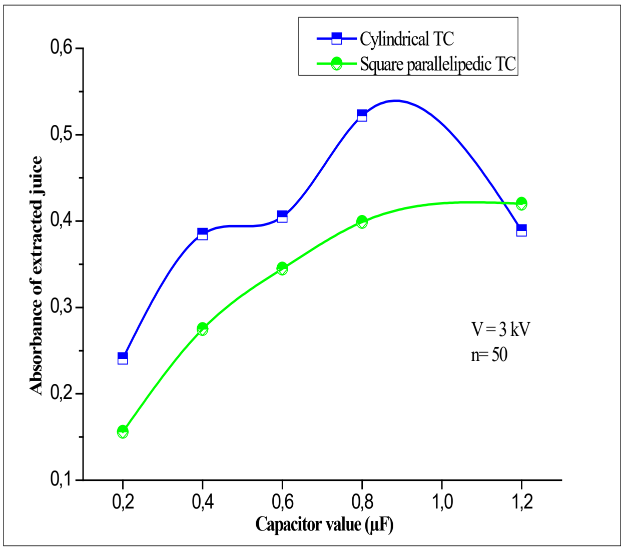


Figure 10 Absorbance of juice extracted for both treatment chambers configuration according to capacitor value (V = 3 kV, n = 50)

Initial results showed that, the mass of extracted juice and the quantity of betanin obtained with a PEF-treated sample increased according to the applied voltage, pulses number or capacitor value (Figures 5-10), for both of treatment chambers. Beyond a determined value of the voltage, the effect of the PEF treatment is inversed due to “oxidation” of the product which causes the opposite effect.

Further efficiencies may be obtained by using cylindrical treatment chamber model compared with the square parallelipedic treatment chamber.

When the treatment chamber presents dissymmetry in the electrodes the electric field became more intense and it makes it possible to penetrate the electric field lines in the deep layers of the tissue to be treated leads to an effective treatment. So, the electroporation process is more efficient in cylindrical treatment chamber compared with the square parallelipedic.

The mass of extracted juice and the quantity of betanine obtained with a PEF treated sample increases according to the applied voltage However, the treatment is more efficient for cylindrical TC model compared with the square parallelipedic TC comprising two electrodes parallel. While for the last TC model, the optimal treatment was obtained for V = 8 kV (m= 31.4 g and Abs= 0.45), for cylindrical chamber greater values of m and Abs were obtained (m= 38.5 g and Abs= 0.522) with lower voltage V = 6 kV (Figure 5 and Figure 8),

As seen in Figure 6 and 9, the mass of extracted juice and the quantity of betanin obtained with a PEF treated sample increased with the pulses number, for the both chambers. However, the treatment was more efficient for cylindrical model compared with the square parallelipedic model and the optimal treatment was obtained for n= 80 pulses (m= 35.1 g and Abs= 0.567), while for the other treatment chamber smaller values of m and Abs were obtained.

On the other hand, the mass m and the absorbance Abs obtained with a PEF treated sample increases with the capacitor value C for both the chambers, up to a determined value and then decreases. The optimal treatment was achieved for C = 1.2 μF (m= 31.2 g and Abs= 0.42), for square parallelipedic treatment chamber greater value was obtained with smaller capacitor used. Therefore, the optimal treatment was obtained for only C= 0.8 μF (m= 36.4 g and Abs= 0.528) showing that the superiority of the cylindrical model of treatment chamber.

4 Energy consumption

The energy consumed during pulsed electric field treatment is presented in Table 1.

Table 1 The maximal values of both the mass *m* and the absorbance *Abs* and the corresponding energy W obtained with each TC

	Cylindrical TC	Square parallelipedic TC
Mass (g)	38.5	31.4
Abs	0.522	0.450
W (J)	432	768

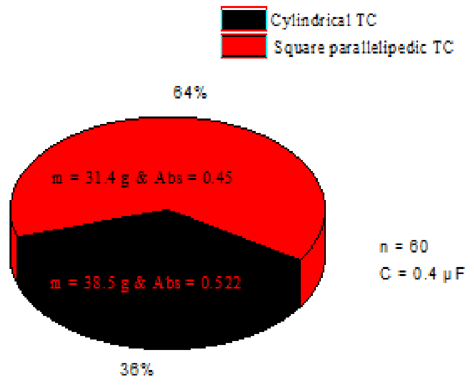


Figure 11 Energy consumed for optimal values

Indeed, an energy saving more of 40 % was achieved for cylindrical model treatment chamber (Figure 11).

5 Conclusion

This paper describes an experimental comparative analysis between two treatment chambers of same dimensions but having either different configuration. The electric field treatment process depends on several parameters. This technology is still unknown and requires careful study.

The present investigation shows that the configuration of treatment chamber is also a significant parameter for pulsed electric field in food processing.

Cylindrical treatment chamber revealed higher additional yields and betanin concentration with consumed energy saving for all studied parameters compared with square parallelipedic treatment chamber. The asymmetrical geometry presented by cylindrical treatment chamber produces a heterogeneous distribution, intense and efficient pulsed electric field for food processing.

Finally, this study must be carried out in the future by a simulation of electric field distribution around the electrodes to better understand the process.

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