The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2022

Volume 21, Pages 295-301

IConTES 2022: International Conference on Technology, Engineering and Science

Experimental Analysis of the Influence of Inter-Electrode Distance in Juice Extraction Processes Using Pulsed Electric Fields

Mohammed Hamza BERMAKI
Djillali Liabès University

Houcine MILOUDI
Djillali Liabès University

Yacine BELLEBNA
Djillali Liabès University

Amar TILMATINE
Djillali Liabès University

Abstract: Nowadays, the pulsed electric field (PEF) is widely used in the food industry. The PEF treatment of different fruits and vegetables before the extraction process has already been used, and its efficiency has already been proven concerning the increase of the quantity of juice extracted, while keeping the aroma and the nutritional quality of the product. The basic concept is to place food in a treatment chamber with two electrodes and use high electric fields to increase the permeability of these cells, a process known as electroporation. An experimental study of beet juice extraction process by pulse electric field has been presented. For this purpose, three static treatment chambers of cylindrical shape with different inter-electrode distances were used. The aim was to determine the influence of the inter-electrode distance in the PEF extraction processes. The methodology of experimental designs was used in this work by developing a fractional factorial design where the inter-electrode distance d was considered as a factor. The results obtained are satisfactory, since it leads us to validated mathematical models. For the same experimental conditions, the treatment chamber with the largest inter-electrode distance gave the best performance in terms of quantity of juice extracted. While the one with the smallest inter-electrode distance is mainly a considerable energy saving but with a low yield in terms of juice mass.

Keywords: Pulse electric field (PEF), Juice extraction, Treatment chambers, Electrodes, Experimental designs.

Introduction

Pulsed electric field (PEF) technology is widely used in the food industry (Šalaševičius et al., 2021; Mohamed et al., 2021; Leone et al., 2022), especially in juice extraction processes for different fruits and vegetables. The PEF extraction process is a multifactorial process (Parniakov et al., 2022). This implies that the development of this technology requires the analysis of the influence of each factor. Preliminary results have already shown the usefulness of having a strong electric field that allows the electroporation of the biological tissues of the food to be treated (Mitchell & Sundararajan, 2005). Also, it is important that the pulse duration is sufficient for a good treatment but should not be too long in order to avoid any heating of the product. In addition, the number of pulses must be optimized in order not to consume too much energy. The distribution of the electric field in the treatment chamber is another parameter to be taken into account in order to improve the efficiency of the PEC extraction processes (Knoerzer et al., 2012; Shorstkii et al., 2019; Arshad et al., 2020). Thus, in this paper, we will focus on another factor that can also have an influence on the yield, namely the inter-electrode distance in the process chamber. Using the design of experiments methodology, a comparative experimental study of three cylindrical chambers has been done. The objective was to analyze the effect of the inter-electrode distance on the yield of the PEF pretreatment on the extraction of beet juice.

Materials and Methods

Pulse Generator

The experimental device used is a capacitor discharge generator. Indeed, the principle is to charge one or a set of capacitors with a high voltage delivered by a DC power supply. This voltage will then be discharged through a spark gap to the treatment chamber where the electrical impulses are produced. A simplified diagram and photography of the experimental bench used are respectively presented in Figure 1.

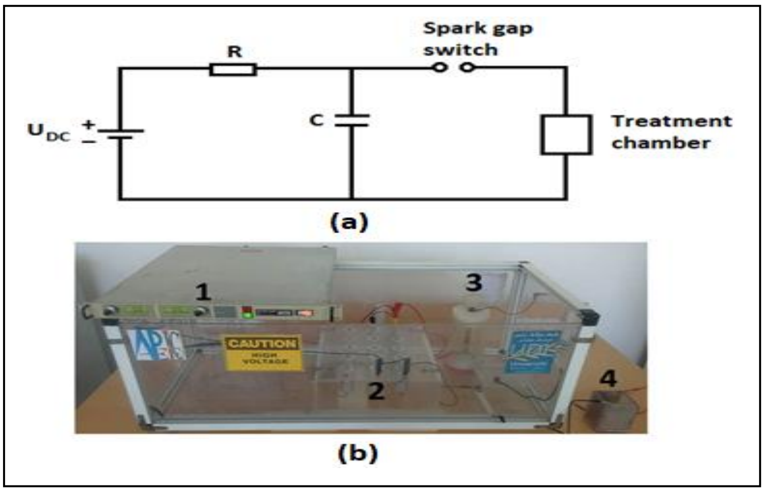


Figure 1. Experimental device (a: Descreptive schematic, b: photography)
1- HV DC power supply, 2-Set of capacitors, 3- Spark gap switch, 4-Treatment chamber

The experimental bench includes three capacitor blocks, each consisting of five 2µF capacitors connected in series. Various connections can be made between the three blocks, which allows a wide choice in terms of pulse duration. As the experimental bench used is based on the principle of charge and discharge of capacitors, the pulse generated is of decreasing exponential form.

Treatment Chambers

Three coaxial cylindrical treatment chambers were used in this work. Each chamber consists of two cylindrical electrodes, one connected to high voltage and the other to ground, and between which the food to be treated is placed. During all the experiments carried out, regardless of the treatment chamber, the applied field was kept constant and equal to 2 kV/cm. For this purpose, the voltage was varied according to the distance D, which gives: V = 2 kV for D = 1 cm, V = 4 kV for D = 2 cm and V = 6 kV for D = 3 cm, as shown in Figure 2.

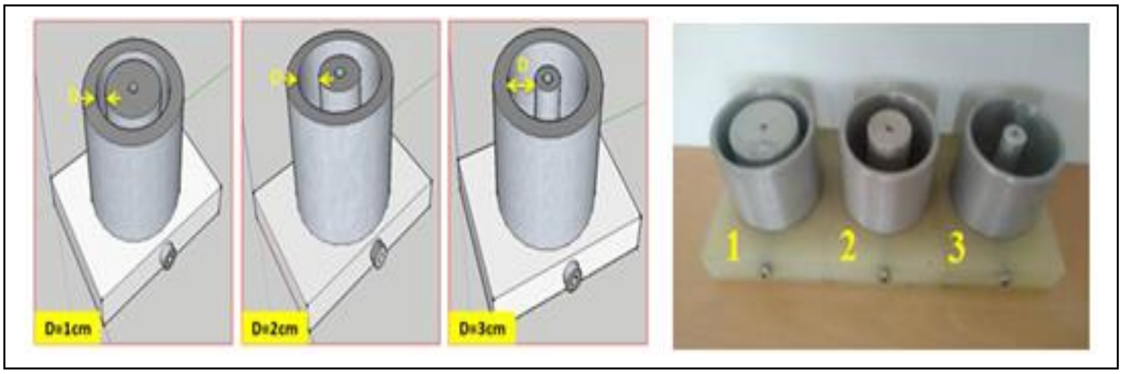


Figure 2. Coaxial cylindrical treatment chambers

Beet Juice Extraction Process by PEF

The beet juice extraction process was used to evaluate the performance of the three cylindrical processing chambers. The experimental design methodology was used and the first step is the parametric study which consists of preliminary experiments to delineate the study intervals of the different factors. All experiments were performed keeping certain factors constant throughout the study, such as:

- Mass of the grated beet sample 120g
- Constant extraction pressure P = 50 kg/cm2
- Total duration of the mechanical pressure Δt = 300 s
- Pulse repetition frequency f = 1 Hz
- Electric field E = 2 kV/cm

The variable factors are :

- Number of pulses n
- Pulse duration T (µs)
- Inter-electrode distance D (cm)

The responses are:

- Extracted juice mass (g)
- Absorbance of betanin
- PEF treatment energy (Joule)

In order to define the study interval of these three factors, a series of experiments as well as preliminary tests were performed while varying one factor at a time. Thus, the study intervals of the three factors were defined as follows:

- Number of pulses n; n min= 40 and n max= 80
- Pulse duration T (µs); T min= 20 µs and T max= 60 µs
- Inter-electrode distance D (cm); D min= 1 cm and D max= 3 cm.

Results and Discussion

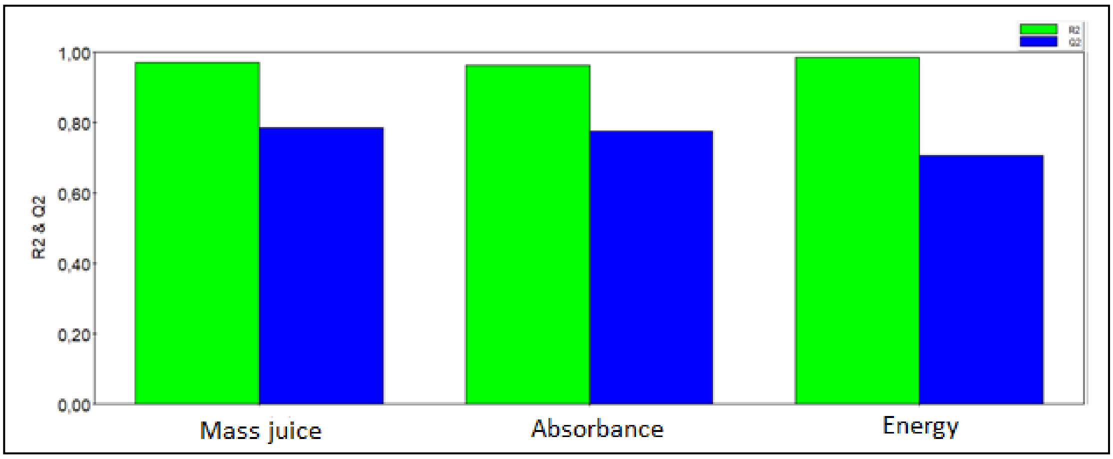
Mathematical Models

A central composite face-centered design (CCF) was performed with 17 experiments carried out and the results are presented in the table.

Table 1. Results of the CCF design experiment

	Variable factors			Responses		
Exp N°	n	T (µs)	D (cm)	m (g)	Abs	W(J)
1	40	20	1	34,30	1,03	32
2	80	20	1	37,40	1,28	64
3	40	60	1	41,16	1,21	96
4	80	60	1	42,70	0,71	192
5	40	20	3	46,70	0,48	288
6	80	20	3	53,50	0,57	576
7	40	60	3	49,80	1,21	864
8	80	60	3	54,30	0,52	1728
9	40	40	2	41,70	0,99	256
10	80	40	2	43,10	0,71	512
11	60	20	2	48,50	0,63	192
12	60	60	2	48,10	0,62	576
13	60	40	1	42,00	1,34	96
14	60	40	3	52,80	0,76	864
15	60	40	2	48,20	0,70	384
16	60	40	2	48,20	0,70	384
17	60	40	2	48,20	0,70	384

The predictive quality of the juice mass, absorbance and energy models is satisfactory since the Q2 and R2 coefficient values presented in Figure 3 are close to the unit. Therefore, the models are validated and can be used for analysis and prediction.



The respective mathematical models of extracted juice mass, absorbance and energy as a function of the factors studied are given by MODDE 5.0 as:

$$m=47{,}46+1{,}73\,n+1{,}56\,T+5{,}95\,d-4{,}50\,n^2$$
$$Abs=0{,}7-0{,}11\,n-0{,}2\,d-0{,}17\,T^2+0{,}25\,d^2-0{,}19\,n*T+0{,}13\,T*d$$
$$W=384+153{,}6\,n+230{,}4\,T+384\,d+80\,n*T+128\,n*d+192\,T*d$$

Effects of Variable Factors on Responses

From the mathematical models, the plots of the effects of each factor on the response are obtained (Figures 4, 5 and 6). It can be seen that for the mass of juice extracted (Figure 4), the inter-electrode distance is by far the most influential factor on the response. Therefore, it is deduced that for the same value of the electric field, higher values of the inter-electrode distance allow a better yield in terms of juice quantity. This can be explained by the fact that the food that is placed in a chamber with a wide inter-electrode space. This will allow it to be better exposed to the PEF and therefore benefit from a better treatment. The number and duration of pulses also positively affect the amount of juice extracted, but to a lesser degree compared to the inter-electrode distance.

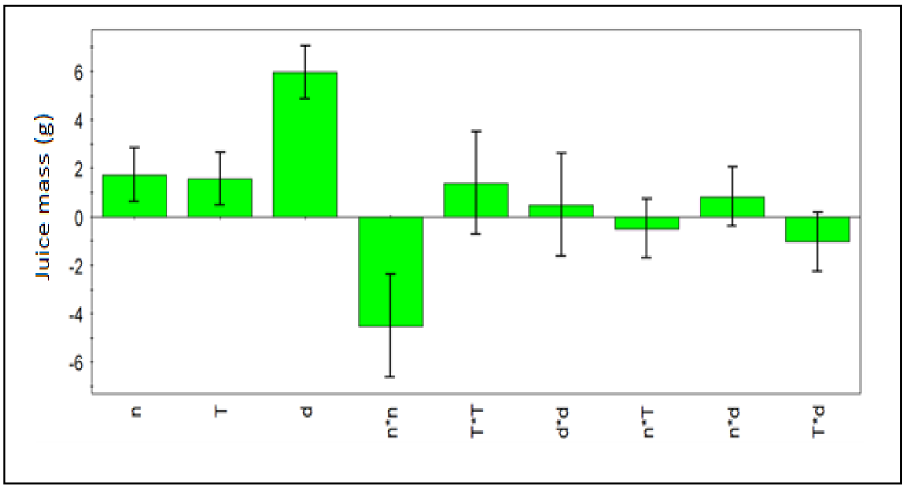


Figure 4. Effects factors plot on mass juice

For the absorbance (Figure 5), the plot shows that the inter-electrode distance is also the most significant factor but in a negative way. Indeed, the absorbance in betanin of the extracted juice decreases for high distances. Since the latter have already shown us that they allow an increase in the quantities of extracted juice. This can lead to an increase of the water content in the beet juice, as the latter is very rich in water (more than 70%), which reduces the betanin absorbance of extracted juice.

The effect of the number of pulses is less important but still negative on this response. The effect of the duration of the pulses is insignificant, one can even say null. However, the interactions of the pulse duration with the number of pulses and the inter-electrode distance are significant and have respectively a negative and positive effect on the response.

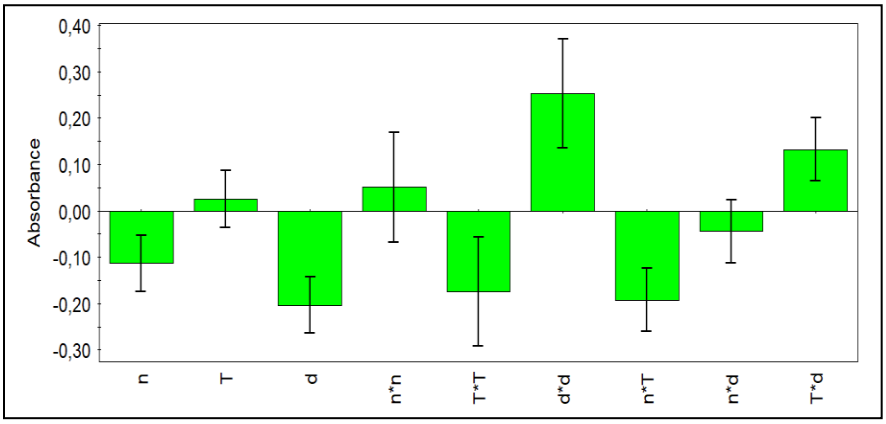


Figure 5. Effects factors plot on absorbance

The energy consumed is proportional to the three factors since it is given by the following formula :

$$W = \frac{1}{2}\, n\, C\, V^2$$

The inter-electrode distance is the most influential factor on energy consumption (Figure 6), which is logical. Because, to keep the electric field constant (2 kV/cm), it was necessary to increase the voltage each time large distances were used.

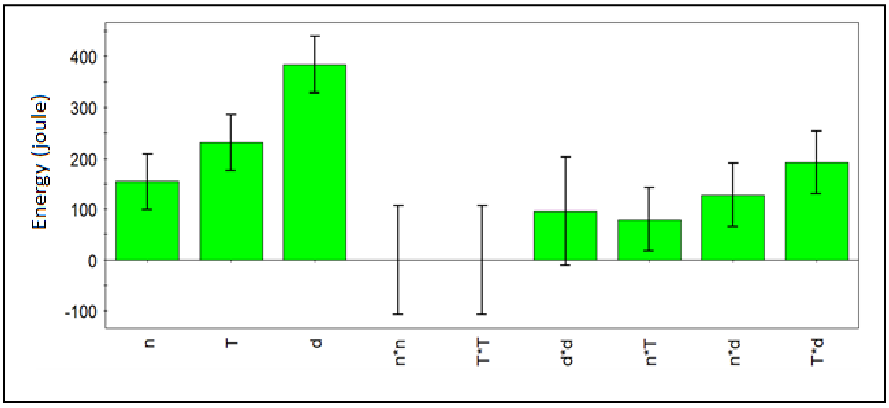


Figure 6. Effects factors plot on energy

Optimization of the Juice Extraction Process by PEF

According to this model, the optimum of the process proposed by MODDE 5.0 which gives the optimal values of the factors to obtain a maximum yield of the extraction process is presented by the Figure 7. Thus, the maximum process yield given by MODDE 5.0 software with a juice mass of 53.06 g and a betanin absorbance of 1.01 was obtained for 48 pulses, pulse duration of 60 µs, and an inter-electrode distance of 3 cm. The energy consumed in this case was 1074.43 joules.

	Factor	Role	Value	Low Limit	High Limit
1	nombre d'impulsions	Free		40	80
2	Durée d'impulsion	Free		20	60
3	Distance inter-électrodes	Free		1	3

	Response	Criteria	Weight	Min	Target	Max
1	masse de jus	Maximize	1	52,9587	54,8589	
2	Absorbance	Maximize	1	1,28245	1,3654	
3	Enérgie	Exclude				

Iteration: 5002 Iteration slider:

	1	2	3	4	5	6	7	8
	nombre d'impulsions	Durée d'impulsion	Distance inter-électrodes	masse de jus	Absorbance	Enérgie	iter	log(D)
1	42,0121	53,0308	1	40,1132	1,2896	51,1155	5001	1,4847
2	48,3156	59,9765	3	53,0773	1,0159	1074,71	5001	0,9693
3	75,6281	25,4816	1	39,0764	1,289	42,7501	5000	1,543
4	48,2977	59,972	3	53,0699	1,0162	1074,3	5002	0,9686
5	48,2771	59,999	3	53,0671	1,0166	1074,43	5000	0,9679
6	75,6281	25,4816	1	39,0764	1,289	42,7501	5000	1,543
7	48,2854	59,9949	3	53,0695	1,0164	1074,51	5000	0,9682
8	48,2767	59,9999	3	53,0672	1,0166	1074,44	5000	0,9679

Conclusion

An experimental study of the beet juice extraction process using PEF has been presented in this paper. For this purpose, three static treatment chambers of cylindrical shape with different inter-electrode distances were used. The aim was to determine the influence of the inter-electrode distance in the PEF extraction processes. The design of experiments methodology was used in this work by developing a fractional factorial design where the inter-electrode distance d was considered as a factor.

The results of the realized FEC design are satisfactory, since it leads us to validated mathematical models. For the same experimental conditions, the treatment chamber with the largest inter-electrode distance gave the best performance in terms of quantity of juice extracted. While the one with the smallest inter-electrode distance allows above all a considerable energy saving but with a low yield in terms of juice mass. Because in an extraction process, the amount of juice extracted is the most important response, and the PEF technology is essentially used to increase the amount of juice extracted. It can be said that the results obtained can confirm that the use of processing chambers with high inter-electrode distances improves the performance of PEF treatment.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

This article was presented as the poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 16-19, 2022.

References

Arshad, R. N. Abdul Malek, Z., Ahmad, M. H., Buntat, Z., Pavan Kumara, C. L .G., & Abdulameer, Z. A (2020). Coaxial treatment chamber for liquid food treatment through pulsed electric field. *Indonesian Journal of Electrical Engineering and Computer Science*, *19*(3): 1169-1176.

Knoerzer, K., Baumann, P., & Buckow,R. (2012). An iterative modelling approach for improving the performance of a pulsed electric field (PEF) treatment chamber. *International Journal of Computer Applications in Chemical Engineering*, *37*, 48-63.

Leone, A.,Tamborrino, A., Esposto, S., Berardi, A., & Servili, M. (2022). Investigation on the effects of a pulsed electric field (PEF) continuous system implemented in an industrial olive oil plant. *International Journal of Foods (MDPI), 11*(18), 2758.

Mitchell, W., & Sundararajan, R. (2005). Electric field distribution in biological tissues for various electrode configurations-a FEMLAB study. *Excerpt from the Proceedings of the COMSOL Multiphysics User's Conference.* Boston.

Mohamed, R., Lemrabout, A., Taleb, R., Kerbouac, A., & Mahmoud, A. (2021). Effect of treatment with electric field pulse on the extraction of Polyphenols. *iKSP Journal of Emerging Trends in Basic and Applied Sciences, 1*(1), 22-29.

Parniakov,O., Lebovka,N., Wiktor, A., Comiotto Alles, M., Hill, K., & Toepfl, S. (2022). Applications of pulsed electric fields for processing potatoes: Examples and equipment design. *International Journal of Research in Agricultural Engineering, 68*(2), 47–62.

Šalaševičius, A.,Uždavinyté, D.,Visockis, M., Ruzgys, P., & Šatkauskas, S. (2021). Effect of pulsed electric field (PEF) on bacterial viability and whey protein in the processing of raw milk. *International Journal of applied sciences (MDPI), 11*(23), 11281.

Shorstkii, I., Sosnin, M., & Khudyakov, D. A. (2019). Continuously pulsed electric field treatment chamber modelling and design. *IOP Conference Series Materials Science and Engineering*, *564*(1), p. 012032). IOP Publishing.

Author Information

Mohammed Hamza Bermaki
Djillali Liabès University
Sidi Bel-Abbès, Algeria
Contact e- mail : *bermaki.hamza@gmail.com*

Yacine Bellebna
Djillali Liabès University
Sidi Bel-Abbès, Algeria

Houcine Miloudi
Djillali Liabès University
Sidi Bel-Abbès, Algeria

Amar Tilmatine
Djillali Liabès University
Sidi Bel-Abbès, Algeria

To cite this article:

Bermaki, M. H., Bellebna, Y., Miloudi, H., & Tilmatine, A. (2022). Experimental analysis of the influence of inter-electrode distance in juice extraction processes using pulsed electric fields *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 21,* 295-301.