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Identification of Electrical Pulse Shape (PEF) characteristics during interaction with liquid substances of varying densities

Identyfikacja charakterystyki kształtu impulsu elektrycznego (PEF) w czasie oddziaływania na substancje ciekłe o zróżnicowanej gęstości

Abstract: *. The article examines the pulse shape during the fixation process of the selected liquid food substances, each characterized by varying resistances. Significant intragroup variations were observed in the signal when different voltages were generated by the pulse generator under the same pulse width. Additionally, intergroup variations in the pulse shape were noted despite identical device settings. A similar trend was identified in dune analysis, where characteristics varied both within a single substance under different interaction voltages and between different substances tested at the same interaction voltage and pulse width. The identified differences, once quantitatively parameterized, will enable optimization of the PEF fixation process. This optimization will consider the resistance of the material being processed, minimizing unit energy consumption and improving overall process efficiency.*

Streszczenie: *W artykule dokonano analizy kształtu impulsu realizującego proces utrwalania wybranych ciekłych substancji spożywczych charakteryzujących się różną rezystancją. Odnotowano istotne wewnątrzgrupowe zróżnicowanie sygnału dla różnych napięć generowanych przez generator i tej samej szerokości impulsu oraz zróżnicowanie międzygrupowe w kształcie impulsu przy tych samych nastawach urządzenia. Podobne stwierdzenie dotyczy analizy wydmowej, której charakterystyka jest zróżnicowana w obrębie jednej substancji, ale zróżnicowanym napięciu oddziaływania oraz między badanymi substancjami przy tym samym napięciu oddziaływania i tej samej szerokości impulsu. Zidentyfikowane różnice pozwolą po ich ilościowej parametryzacji zoptymalizować proces utrwalania PEF w funkcji rezystancji utrwalanej materii minimalizując nakład energii jednostkowej oraz poprawiając skuteczność procesu.*

Keywords: Pulsed Electric Field (PEF), electric pulse, optimization, food preservation
Słowa kluczowe: pulsacyjne pole elektryczne (PEF), impuls elektryczny, optymalizacja, utrwalanie żywności

Introduction

Pulsed Electric Field (PEF) technology is regarded as a promising method for inactivating microorganisms in food. Pulsed electric fields with intensities ranging from 5 to 50 kV/cm enable microorganism inactivation at lower temperatures compared to conventional heat treatment methods. The application of PEFs, characterized by high intensities and durations ranging from microseconds to milliseconds, can induce temporary or permanent changes in cell membrane permeability. The effects of PEFs on cell membranes have been extensively studied in scientific disciplines such as cell biology, biotechnology, medicine, and food technology [1,2]. The primary mechanism of microbial inactivation in pulsed electric field (PEF) technology is microporation of the cell membrane. However, the exact process remains partially understood and continues to be an active area of research. Non-thermal food preservation methods, such as PEF, are gaining importance due to increasing consumer demand for foods with a high nutritional value. PEF is commonly used to process juices like orange and apple juice, effectively preserving their sensory qualities while extending shelf life. Beyond juices, PEF is also applied to liquid foods such as yogurt, sauces, milk, tomato juice, carrot juice, peas, egg pulp, and other similar products. In recent years, significant research efforts have been directed toward developing technologies that achieve microorganism inactivation at lower temperatures compared to conventional heat treatments, aiming to preserve food quality while ensuring safety [3]. The use of pulsed electric fields (PEF) in food processing significantly reduces energy consumption. It serves as an alternative to conventional heat treatment methods for liquid food products and has the potential to partially replace them [4,5] The basic principle of pulsed electric field (PEF) interaction involves the application of short pulses of high-intensity electric fields, typically ranging from 10 to 80 kV/cm, with durations spanning from microseconds to milliseconds. This process relies on the interaction of electrical pulsed currents applied to the product placed between a set of electrodes. To date, the influence of pulse shape on the intensity of microbial degradation has not been fully established. PEF is an environmentally friendly technique with versatile applications in food processing, including microorganism and enzyme inactivation, recovery of bioactive compounds, dehydration, freezing, quality enhancement, and more [6-9]. Due to the complexity of mathematically describing the generation and propagation of discharges in these environments, the advancement of PEF technology necessitates the study and development of physical models. In future it is worth to use different methods of simulations [10]. Wesołowski et al. [11,12] propose a simplified model of pulse discharge in liquid environments. The results derived from modeling this process are expected to significantly streamline physical testing procedures by enabling the selection of devices capable of generating pulses with desired parameters. The proposed model and computational procedure facilitate the simulation of discharge development, allowing for the determination of instantaneous current and voltage values within the arc column. This supports the optimal selection of capacitors and voltage settings for pulse generators. Thermal analyses performed as part of the study take into account varying environmental parameters, enabling the determination of temperatures within the discharge column. Additionally, due to the pulsed operation of PEF devices, the calculations incorporate the analysis of the cooling process in the working area, providing insights into the required intervals between pulses.

Purpose, scope and methodology

The purpose of this study was to characterize the shape of the electrical pulse generated between the electrodes of a chamber containing a fluid. The scope involved identifying the characteristic points of the electric pulse waveform in relation to the density of the liquid in the device chamber. Six types of liquids were selected for the study: apple juice, orange juice, grapefruit juice, tomato juice, canola oil, and water (used as a reference material). All liquids were thermally stabilized, maintaining a temperature of 20°C during their exposure to PEF. The experiments were conducted using a ScandiNova M100 bench located at the Centre for Innovation and Research on Prohealthy and Safe Food, Agricultural University of Cracow (Fig. 1).

Fig. 1. View of the control panel with measurement instrumentation and PEF interaction chamber.

In contrast, figure 2 shows the ScandiNova M100 device for generating pulsed electric field.

Fig. 2. View of the ScandiNova M100 test stand with a generator unit for PEF generation.

The device allowed for the control of key parameters important for the pulsed electric field interaction process on the liquid, within the following ranges: a) pulse width of the interaction from 1 μs to 10 μs, b) interaction voltage range from 2 kV to 56 kV, c) pulse frequency range from 0.2 Hz to 100 Hz, d) number of pulses ranging from 1 to 1000, e) a stationary sterilization cell with a capacity of 200 ml (Fig. 3).

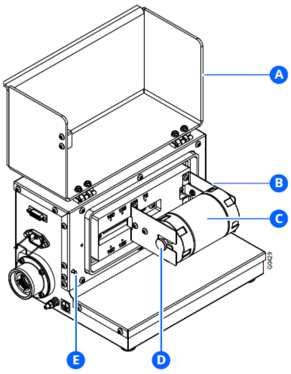

Fig. 3. Diagram of the PEF impact chamber: A) Cover - Safety feature. Must always be closed during operation; B) Hoider – Holder for the jar. Serves as connector for the electrodes; C) Screw – For securing the jar in the holder. Can be moved between jars; D) D- Momentary switch- Safety feature. The PEF chamber cannot be operated with the momentary switch in extended position

Three different electric field voltage combinations were used in the experiment: 5 kV, 25 kV, and 50 kV, to fully utilize the device's capabilities. The device was computer-controlled, allowing all required PEF impact settings to be adjusted via a text interface (fig.4).

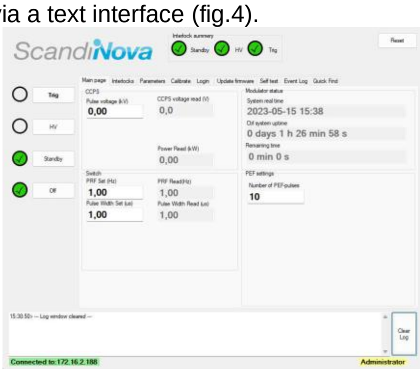

Fig. 4. View of the operating interface of the PEF device.

The recording of the characteristics of the electrical pulse was carried out using an oscilloscope. The working area, i.e. the space between the electrodes, was a constant value.

Results

The shape of the pulse generated by the PEF device was influenced by the electrical properties of the substance it interacted with. The key parameter affecting the characteristics of the pulse was the electrical resistance of the material between the electrodes. Differences in the physicochemical structure of the substance determined its electrical conductivity, which in turn affected the course and shape of the PEF pulse signal. Using water as the reference substance, with a voltage of 5 kV and a pulse width of 1 μs, the shape of the electrical pulse is shown in figure 5.

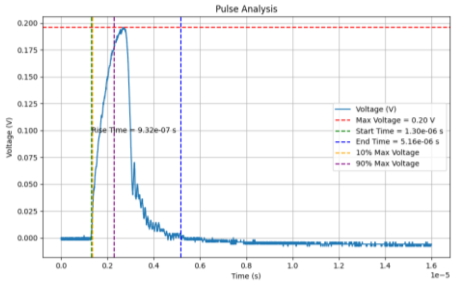

Fig. 5: Characteristics of the recorded signal in the case of an interaction voltage of 5kV

Figure 6 shows the characteristics of the signal recorded for the same input parameters of the device in the case of interaction with apple juice.

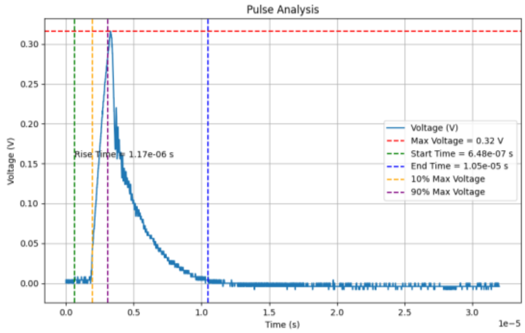

Fig. 6. Characteristics of the recorded signal in the case of 5kV interaction voltage

Figure 7 shows the signal characteristics recorded for the same device input parameters when interacting with tomato juice.

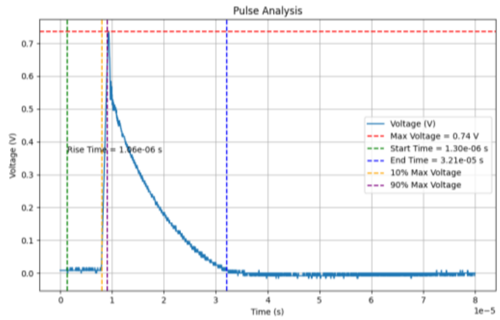

Fig. 7. Characteristics of the recorded signal in the case of an interaction voltage of 5kV

Figure 8 shows the characteristics of the signal recorded for the same input parameters of the device in the case of interaction with rapeseed oil.

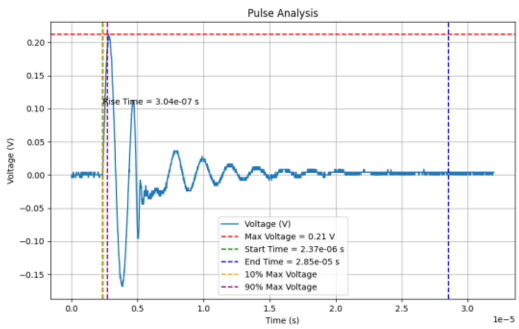

Fig. 8. Characteristics of the recorded signal in the case of an interaction voltage of 5kV

Slightly different characteristics were recorded for water as a reference substance and the application of a voltage of 50kV and a pulse width of 1μs electrical pulse shape, which is shown in figure 9.

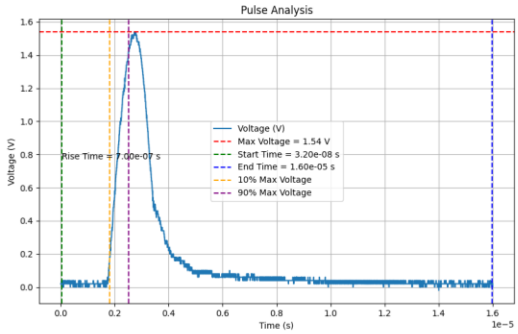

Fig. 9. Characteristics of the recorded signal in the case of an interaction voltage of 50kV

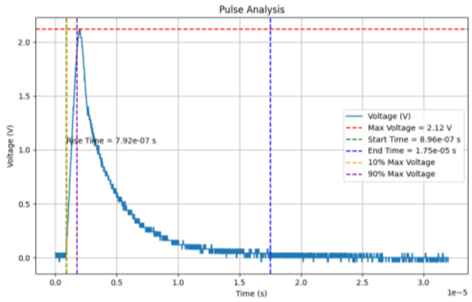

Fig. 10. Characteristics of the recorded signal in the case of an interaction voltage of 50kV

Figure 10 shows the characteristics of the signal recorded for the same input parameters of the device in the case of interaction with apple juice.

Figure 11 shows the characteristics of the signal recorded for the same input parameters of the device in the case of interaction with tomato juice.

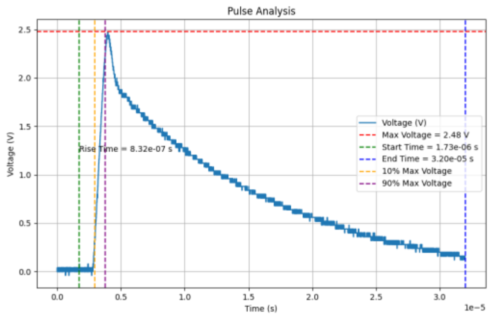

Fig. 11. Characteristics of the recorded signal in the case of an interaction voltage of 5kV

Figure 12 shows the characteristics of the signal recorded for the same input parameters of the device in the case of interaction with rapeseed oil.

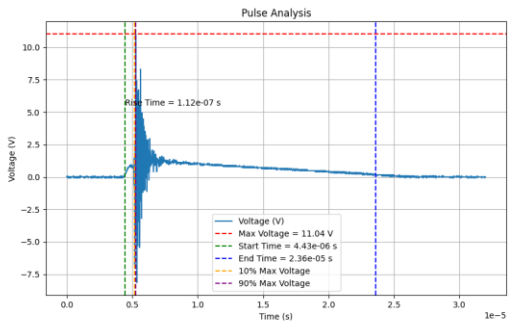

Fig. 12. Characteristics of the recorded signal in the case of an interaction voltage of 50kV

Figure 13 shows the amplitude spectrum using a voltage of 5kV and a pulse width of 1μs and the treated substance as water.

Figure 14 shows the spectral characteristics recorded for the same input parameters of the device in the case of interaction with apple juice.

Figure 15 shows the spectral characteristics recorded for the same input parameters of the device in the case of interaction with tomato juice.

Figure 16 shows the spectral characteristics recorded for the same input parameters of the device in the case of interaction with rapeseed oil.

Figure 17 shows the amplitude spectrum using a voltage of 50kV and a pulse width of 1μs in the case of interaction with rapeseed oil.

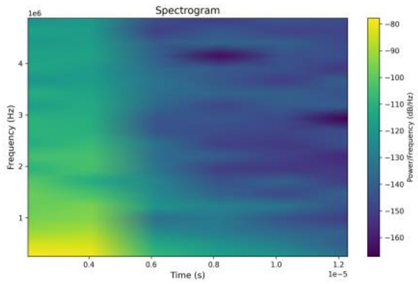

Fig. 13. Spectral characteristics of the recorded signal in the case of 5kV interaction voltage.

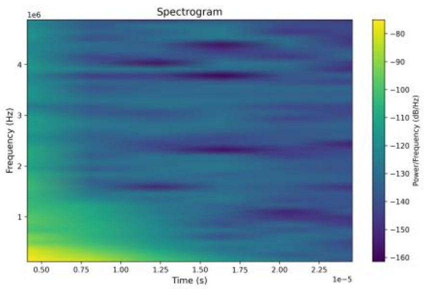

Fig. 14. Spectral characteristics of the recorded signal in the case of 5kV interaction voltage.

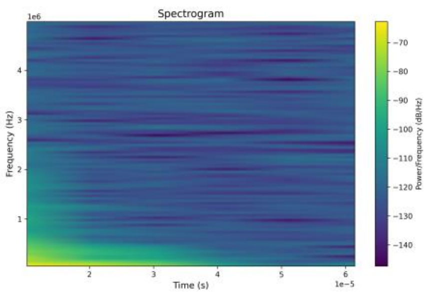

Fig. 15. Spectral characteristics of the recorded signal in the case of 5kV interaction voltage.

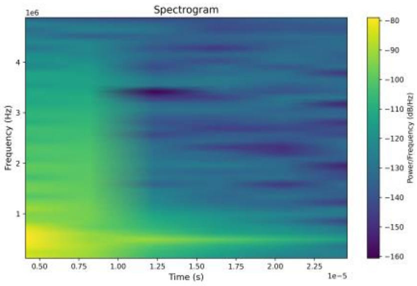

Fig. 16: Spectral characteristics of the recorded signal in the case of an interaction voltage of 5kV

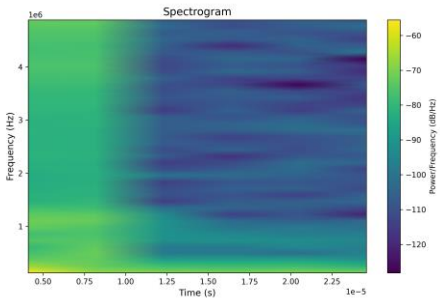

Fig. 17. Spectral characteristics of the recorded signal in the case of 50kV interaction voltage

Conclusion

Significant intragroup variation in the signal was observed for different generator voltages with the same pulse width, as well as intergroup variation in pulse shape at the same device settings. A similar pattern was noted in the analysis of the dunes, where characteristics varied within a single substance at different interaction voltages, and between substances tested at the same interaction voltage and pulse width. The identified differences, once quantitatively parameterized, will enable optimization of the PEF fixation process based on the resistance of the material being treated, thereby minimizing unit energy consumption and improving process efficiency. However, the observed relationships require further study to fully understand and detail the underlying phenomena.

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