JOURNAL OF APPLIED SCIENCE AND SOCIAL SCIENCE
eISSN 2229-3113 pISSN 2229-3205
Volume 15 Issue 04, April 2025
Impact factor: 2019: 4.679 2020: 5.015 2021: 5.436, 2022: 5.242, 2023: 6.995, 2024 7.75

# PULSED ELECTRIC FIELD: A SUSTAINABLE APPROACH FOR NON-THERMAL FOOD PROCESSING

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**Abstract:** This paper explores the potential of Pulsed Electric Field (PEF) technology as a sustainable, non-thermal method for food processing. PEF applies short, high-voltage electric pulses to liquid and solid food products to achieve microbial inactivation, enhance mass transfer, and preserve nutritional and sensory qualities. The study highlights the working principles of PEF, its integration into industrial systems, and its effectiveness in improving oil extraction and minimizing energy consumption. PEF is shown to be a promising technology for meeting the growing consumer demand for minimally processed, high-quality foods.
**Keywords:** Pulsed electric field (PEF),non-thermal processing, microbial inactivation, electroporation, food quality, oil extraction, energy efficiency, food preservation, food processing innovation.

**Introduction.** In recent years, the demand for innovative, non-thermal food processing technologies has significantly increased, aiming to overcome the limitations of conventional thermal methods. Among these emerging technologies, Pulsed Electric Field (PEF) processing stands out due to its ability to enhance product safety and quality without the adverse effects of heat. PEF processing involves applying short bursts of high-voltage electric fields—typically ranging from 20 to 80 kV/sm—to liquid foods placed between two electrodes for durations ranging from microseconds to milliseconds. For solid foods, due to the larger treatment chamber and power limitations of the pulse generator, lower field strengths of 1 to 8 kV/cm are generally used. These electric field pulses can be applied as exponentially decaying, square, bipolar, or oscillatory waveforms, often at high repetition rates—up to 3000 pulses per second—to ensure uniform treatment of the entire food volume. PEF technology serves as a novel method for pasteurization, utilizing high-intensity electric fields to inactivate microorganisms or to alter the structural integrity of food materials. This non-thermal approach preserves the color, flavor, nutritional value, and texture of food products far better than traditional heat-based treatments.
Consequently, PEF has gained significant interest in food engineering as a promising, energy-efficient solution for producing safe, high-quality, and functionally enhanced food products. In the context of oilseed processing, particularly flaxseeds, PEF treatment improves the

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permeability of cell membranes, thereby enhancing oil extraction efficiency during pressing or subsequent processing stages.

Pulsed Electric Field (PEF) processing involves the application of a series of short, high-voltage electric pulses. These pulses disrupt the cell membranes of vegetative microorganisms by creating pores or enlarging existing ones—a phenomenon known as electroporation. As a result, intracellular contents leak out, leading to the loss of vital metabolic activity such as growth and division, ultimately causing microbial inactivation. The effectiveness of microbial inactivation using PEF largely depends on both processing parameters and equipment design, including: Electric field strength,Treatment duration, Pulse frequency, Pulse width, Processing temperature. Additionally, several product-related parameters influence the efficacy of microbial inactivation: pH level (acidity), Presence of antimicrobial or ionic compounds, Electrical conductivity, Mean ionic strength

Figure 1. Typical PEF Pulse Shapes

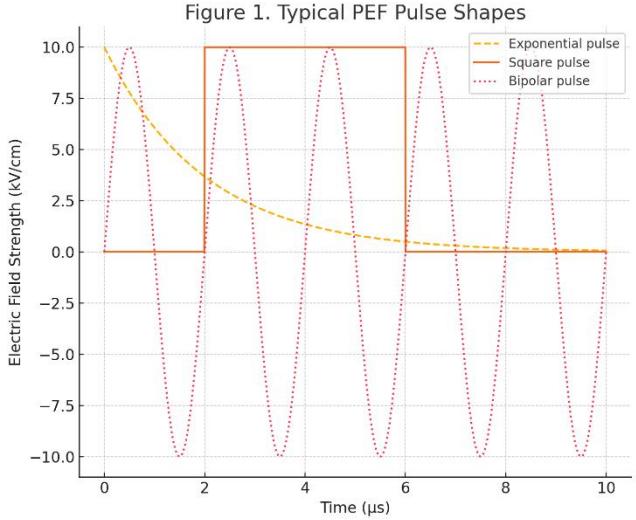
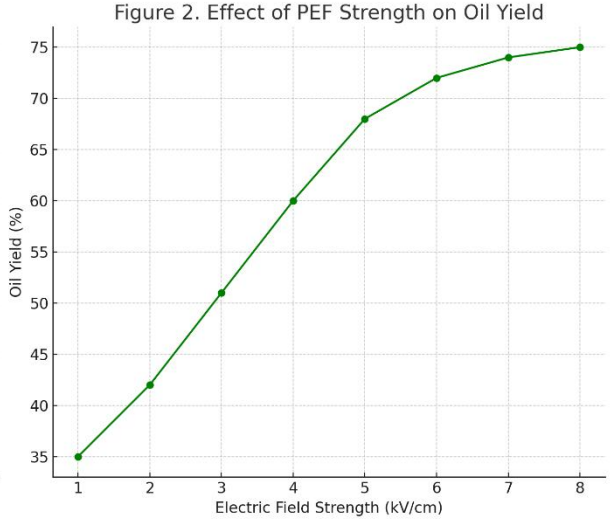



Figure 2. Effect of PEF Strength on Oil Yield




The electric pulses used in PEF treatment may take various waveforms, including exponentially decaying, square, and bipolar forms, depending on the desired effect (Figure 1).

As shown in Figure 2, increasing the electric field strength from 1 to 8 kV/cm significantly improves the oil yield, which supports the application of PEF as a pre-treatment for oilseed pressing.

**Working Principle of Pulsed Electric Fields.** The core principle of Pulsed Electric Field (PEF) technology is the application of short, high-intensity electric pulses—typically ranging from 10 to 80 kV/sm and lasting from microseconds to milliseconds—to a food product placed between two electrodes. The treatment is usually performed at room temperature or slightly above or below it. The total treatment time is defined by the number of pulses and their effective duration. Due to the presence of charged ions in food products, they exhibit a certain level of electrical conductivity. When the electric field is applied, the current flows through the liquid food and distributes uniformly via the charged molecules. This results in electroporation of microbial cell

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membranes, leading to permanent damage and microbial inactivation.

PEF is classified among non-thermal food processing technologies, which aim to preserve the nutritional value, such as vitamins, minerals, and natural flavors, while consuming less energy compared to conventional thermal processes.

Additionally, PEF is used in biotechnology and genetic engineering for applications such as cell fusion and electroporation. The process involves placing the food product between a set of electrodes, where the distance between them defines the treatment gap. Pulses may be delivered in various forms, including exponentially decaying, square wave, bipolar, or oscillatory shapes, depending on the desired outcome. After treatment, the food is aseptically packaged and stored under refrigeration. PEF systems can be easily integrated into existing food production lines. For solid food products and cell disruption applications, a typical PEF processing setup includes a pulse generator and a treatment chamber unit.In applications related to liquid food pasteurization, the PEF system generally consists of a raw material reservoir, a liquid pump, a pulse generator, a treatment chamber, a packaging unit, and optionally, heating/cooling modules and a final product storage space.

These processing lines can be sanitized using Clean-In-Place (CIP) or Steam-In-Place (SIP) systems, ensuring compliance with hygiene and food safety regulations.

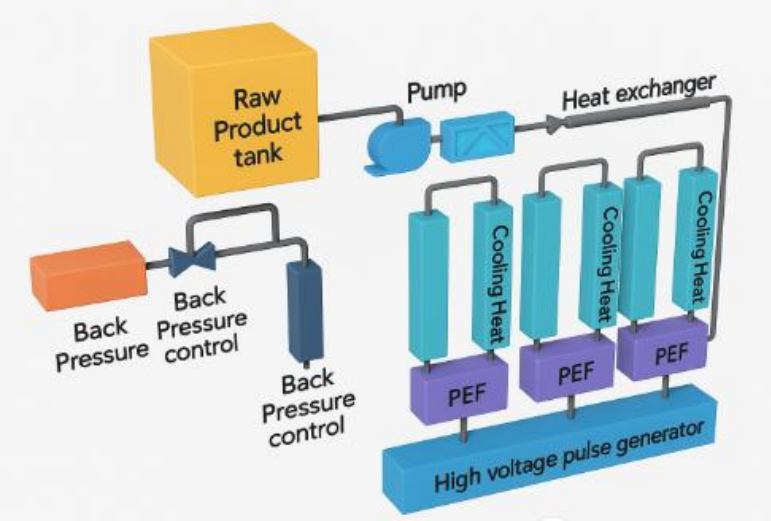


Figure 3. A diagram illustrating the various components of the pulsed electric field (PEF) processing system

**Discussion of results**. Pulsed Electric Field (PEF) technology is based on the application of high-voltage electric pulses to food products placed between a set of electrodes that define the treatment gap within the PEF chamber. The core system consists of a high-voltage pulse generator, a compatible liquid handling system, and a treatment chamber equipped with necessary monitoring and control devices .The food product is introduced into the treatment chamber either statically or in a continuous flow. Inside the chamber, the two electrodes are separated by an insulating material to prevent electrical short circuits. When high-voltage pulses are generated, they are applied to the electrodes, which then deliver the electric field directly to

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the product positioned between them.As a result, the food is exposed to an intense electric field, responsible for inducing irreversible electroporation in microbial cell membranes. This disruption leads to microbial inactivation while preserving the quality and functionality of the food.

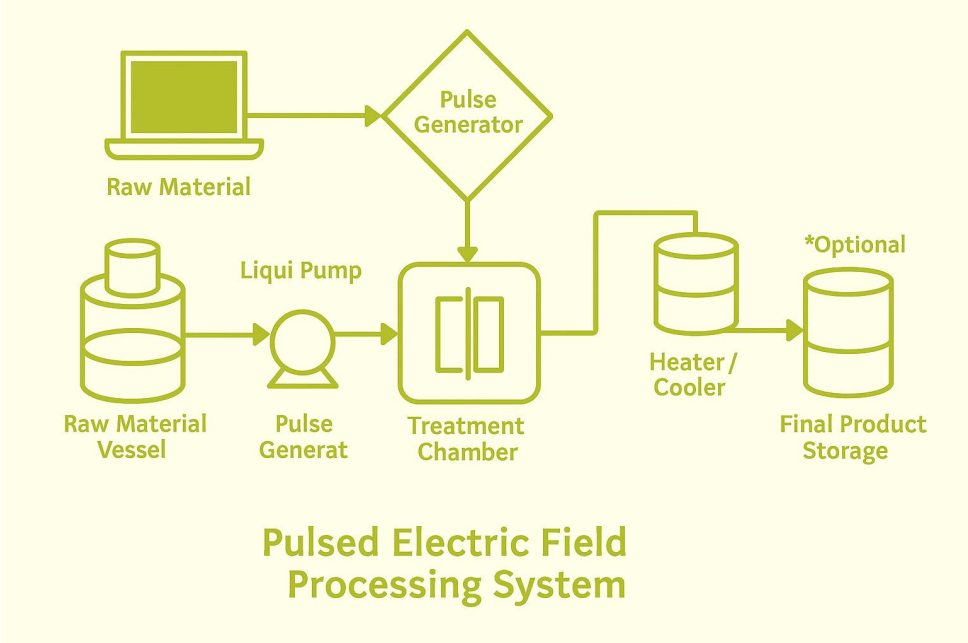


Figure 4. Block diagram of a pulsed electric field food processing system with main components

**Conclusion.** Pulsed Electric Field (PEF) technology, as an emerging non-thermal food processing method, has gained significant attention for its ability to preserve the nutritional and sensory qualities of food while reducing energy consumption. Despite the promising nature of this method, its application remains limited due to the relatively small number of comprehensive studies and industrial implementations compared to conventional thermal treatments. This research has demonstrated that the use of PEF technology in processing agricultural raw materials—such as oilseeds—can substantially enhance process efficiency. The application of high-voltage electric pulses facilitates the permeabilization of cell membranes, improving mass transfer processes like oil extraction, microbial inactivation, or dehydration. As consumer preferences continue to shift toward minimally processed foods with fresh-like characteristics, the food industry requires technologies that can meet these expectations without compromising food safety or quality. PEF offers a practical solution for processors to achieve this goal. It allows for the treatment of liquid foods and the pre-treatment of solid foods before pressing, drying, or other unit operations. In summary, PEF technology presents a forward-looking, energy-efficient alternative to traditional methods. Its integration into industrial food processing lines has the potential to advance product quality, sustainability, and consumer satisfaction in line with current market trends.

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