Laboratory setup for converting mains voltage into a pulsed electric field with automated monitoring and control systems

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Abstract. This paper describes a setup that converts mains voltage into a pulsed electric field (PEF) with a wide range of frequencies, pulse duration and tension in the layer of the processed material. The use of digital technology and inline batch processing enables automated reporting of processing times (exposures); loading and unloading of the process chamber. Monitoring of the chamber processes and feedback from the control unit automatically maintains the PEF parameters required for processing in accordance with the calculated dose. The proposed device with the removable process chambers can process both bulk materials and vegetable raw materials in the fermentation process to improve the taste as well as the organoleptic properties of the resulting products.

1. Introduction
There are some methods for improving seed quality, controlling pathogenic mycoflora and bringing seeds out of dormancy. Many scientists believe that pulsed electric field (PEF) exposure is the most effective, as confirmed by the large number of publications and invention patents devoted to this problem.

Researchers G.P. Starodubtseva, S.A. Livinsky, S.I. Lyubaya et al. studied pre-sowing processing of winter wheat seeds by PEF [1,2]. Yan, Zhou, Song [3] increased the viability of aged cotton seeds. There are also many publications on the cultivation of potato seed tubers from botanical seeds (BSP), which have low germination due to long emergence from dormancy – from 4 to 9 months (Anisimov et al., [4]; Statsyuk, [5]; Cramariuc [6]). Laboratory and field tests have shown an increase in seed germination of up to 30 % and yields by 17 %.

The technological processes used by scientists in different countries for seed processing vary dramatically, e.g. the exposure varies from a microsecond to 10 hours, the pulse strength and repetition rate vary by hundreds of times.

Mastepanenko, Rubtsova, Okashev [7] used PEF processing of vegetable raw materials during fermentation to improve taste qualities and eliminate specific aftertaste of vegetable raw material products. Shorstkii, Koshevoi [8] used sunflower seed oil extraction to improve product quality when using physical factors [9].

Patent searches have shown numerous developments of seed and plant material pre-treatment setups which mostly remain at the stage of patents for invention (Spirov et al., 2010 [10]; Starodubtseva, Livinsky, Rubtsova, Lyubaya, 2018 [2]).
The studied setups lack control of processes occurring in the process chamber, automatic reporting of processing time (exposure), mechanized loading and unloading of the process chamber, explanation about the mechanism of action of the pulse electric field on the seed and plant raw material. These factors confirm the relevance of our research.

The purpose is to design, manufacture and test a laboratory setup with automated monitoring and control systems.

2. Materials and methods

In 2019, based on the studied pre-sowing processing setups and experience gained, we designed and manufactured a laboratory setup, which has a set of new solutions for improvement. Figure 1 shows a block diagram of this setup.

Figure 1. Block diagram of a laboratory setup for converting mains voltage to PEF.

HVS – high voltage source, VI – voltage inverter, CU – control unit, CS – current sensor, VS – voltage sensor, PC – process chamber, FPC – fermentation process chamber, US – unlocking sensor, LS – locking sensor, Ph – photocell

The structural diagram of the laboratory setup (Fig. 1) includes a high voltage source – HVS, loaded on a voltage inverter – VI, the load – LI is the process chamber – PC, where the processing happens, and to which the inverter is connected through a current sensor – CS. A voltage sensor – VS allows measuring the voltage in the process chamber. The current, voltage, unlocking and locking sensors are connected to a control unit – CU which controls the operation of the setup according to data received from the operator. An unlock sensor (US) and a lock sensor (LS) are connected to the process chamber and linked to the photocell (Ph) and the microcontroller unit for automatic reporting of processing times.
3. Results and Discussion

Figure 2 shows a general view of a setup for converting mains voltage to PEF.

The setup consists of the following elements: a control setup, which contains a converter of line voltage into a pulsed electric field (1); a hopper for backfilling of the processed material (2); a power supply (3); a process chamber with an adjustable distance between vertically positioned electrodes from 0.001 to 0.045 m, which eliminates an air gap between the potential electrode and the processed material layer (4); an autotransformer (5) (Fig. 2). Table 1 shows the main technical parameters and characteristics of the setup.

Table 1. The main technical parameters and characteristics of the setup.

| Indicators                  | Data                      |
|-----------------------------|---------------------------|
| Rated supply voltage        | 380/220 V                 |
| Power supply frequency      | 50 Hz                     |
| Voltage pulse duration      | 10–50 µs                  |
| Pulse repetition frequency  | 10 Hz – 100 MHz           |
| Processing method           | Inline & batch            |
| Time to failure             | Not less than 1000 h      |

Figure 2. A general view of a laboratory setup for converting mains voltage to PEF.
1. control unit; 2. hopper for backfilling the processed material; 3. unlocking and locking sensors of the process chamber, photocell; 4. process chamber; 5. autotransformer

The electrodes in this setup are not positioned horizontally, as in many setups, but vertically, thus eliminating voltage losses due to the air gap between the electrode and the processed material layer, and greatly simplifying the process of loading and unloading the seeds from the process chamber.
We developed a mechanism for changing the electrode spacing which allows the electrode gap to be adjusted to an accuracy of 1 mm, due to a lever-mechanical device that moves one of the electrodes without disassembling the process chamber (Fig. 3).

Figure 3. Electrode spacing adjustment mechanism

Based on the laboratory data, the operator uses the front panel display to set the processing mode parameters: pulse duration and frequency, exposure (processing duration) and the calculated field strength in the seed layer. Then the operator switches on 'start processing' in the menu. The processed material enters the process chamber. Our automatic loading and unloading method for the process chamber allows the process to proceed as follows: after the operator switches on 'start processing' in the menu, the flap opens automatically, and backfilling of the material into the process chamber begins. A light-sensitive relay is responsible for filling the process chamber, which sends a signal to the control unit when the chamber is full. The signal is followed by locking the upper flap of the process chamber, then the material processing starts automatically.

At the end of the processing, the time sensor sends a signal to the lower flap sensor in the process chamber and the processed material enters the container for further packaging. At the end of the unloading process, the bottom flap closes automatically, followed by a signal to unlock the top flap and the process repeats, so that there is a continuous inline process.

The fermentation of vegetable raw materials uses a conveyor-type process chamber. The processing proceeds as follows: from the hopper the material passes on to the conveyor belt, where the layer is smoothed by special dielectric protrusions on the belt, then the material passes between the electrodes where it is processed by a pulsed electric field according to parameters set by the operator. A control unit with sensors and microcontroller devices monitors the process.

The digital setting of the processing modes and the feedback between the process chamber and the control unit, using current and voltage sensors, allow adjusting the processing dose automatically as there is a change in the moisture, contamination and injury of the processed material.

Scientists from SsSAU have proposed and patented a method for processing plant raw materials, which differs from existing ones by processing raw materials with a pulsed electric field (PEF) in the fermentation process.
Rolling the leaves and soft stems of the plant material releases the juice. Its interaction with oxygen carries out enzymatic processes and forms the flavour and aroma of the product. Exposure of PEF to the processed product activates the fermentation process and intensifies biochemical processes at the intracellular level, in part by accelerated removal of water, so there is no rapid souring of the raw material. The product acquires a specific flavour and aroma and the characteristic aftertaste of the vegetable raw material disappears or is considerably weakened.

It is possible to explain the effect of PEF on the fermentation process, namely the intensity of biochemical processes and faster evaporation of water, using the results obtained by the American scientist, Nobel laureate Peter Agre, who examined the mechanism of water movement through cell membranes.

Peter Agre discovered a channel that allows water to pass through the cell membrane. The channel has a narrow slit in the centre and a widening at the opposite ends. At the narrowing point, the diameter of the pore is slightly larger than the diameter of the water molecule and, depending on external conditions, water can both enter and leave the cell at high velocity [11].

The aquaporins discovered by Peter Agre, the underlying water pores, are the biochemical basis for a significant area of physiology, medicine and to explain the mechanism of action of physical factors on the processes occurring in seeds during their processing by PEF, the fermentation and drying processes of plant raw materials [11].

4. Conclusion
We have concluded that processing in a low-frequency (LF) field (10–300 Hz) brings water more intensely into the cell, while fermentation and drying of raw materials needs high-frequency fields (hundreds of MHz).

We have the task of proving the effect of an external pulsed electric field on the membrane potential, and hence on the flux of water ions into and out of the cell.

The developed flow-port automated method of loading and unloading the material from the process chamber during the treatment of biological objects allows for numerous experiments with a high degree of reliability and accuracy, which will help to explain the mechanism of action of the electromagnetic field on biological objects and exclude the influence of the human factor on the obtained results.

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