ASPECTS REGARDING THE PRESERVATION OF FOOD PRODUCTS USING HIGH VOLTAGE PULSED ELECTRIC FIELD

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ABSTRACT

Food preservation is an important link in ensuring their quality. The ways in which this desideratum is achieved include a wide range of conservation, thermal and athermal techniques. The paper presents aspects regarding the preservation of food products using the high voltage pulsed electric field, as well as the current stage of the realization of technical equipment that uses this technology.

INTRODUCTION

Food security is currently one of the main issues within the social policy of any civilized country.

Foods are biological substances from agriculture which, in order to be consumed for a long time, must be subjected to operations designed to increase their shelf life unaltered. This is possible by applying primary conditioning or industrialization methods, in which case finished consumer products are obtained and whose shelf life is often longer than conditioning.

Microorganisms acting on agri-food products have the greatest contribution to their qualitative depreciation and, in terms of temperature behavior, they can be grouped as follows:

- psychrophilic or cryophilic microorganisms: they have the capacity to grow at low temperatures between -10^0 C and +8^0 C;
- mesophilic microorganisms: they are the most harmful microorganisms and have a development range between 0-45^{0}C;
- thermophilic microorganisms: they have the capacity to grow at high temperatures between 30 - 75 ^{0} C.

Increasing the shelf life of food in healthy conditions can be achieved by various methods which, in general, can be classified as follows:

- separation of microorganisms by physical processes;
- reducing to stopping the development of microorganisms;
- destruction of microorganisms by various means;
- combined methods.

Taking into account the characteristic biological principle, the following classification of conservation processes can be performed:

• anabiosis or the biological principle of latent life: it is based on slowing down the vital phenomena of both harmful products and microorganisms;

• cenoanabiosis: consists in ensuring favorable conditions for the development of certain microorganisms with bacteriostatic action or biochemical maturation processes;

• abiosis or lack of life: consists in the destruction of microorganisms in products using external agents.

The condition of anabiosis of a food product can be achieved by the following means:

a) *physical*:

- refrigeration (psychoanabiosis) and which consists in keeping the products at low temperatures, above the freezing point;
- freezing (cryoanabiosis) and which consists in freezing part of the water contained within the product;
- drying (xeroanabiosis); implies the

decrease of the water content of the product below the limit necessary for the development of the vital processes of the biological agents;
- salting (haloosmoanabiosis); causes an increase in osmotic pressure through partial dehydration of microorganisms;
- sugaring or the addition of sugar (sacchroosmoanabiosis); is based on the realization of the plasmolysis phenomenon;
b) *chemical*:
- artificial acidification, using acetic acid (acid anabiosis);
- storage in spaces with inert gases such as CO_2 or N_2 (anoxyanabiosis);
- storage in places under pressure of carbon dioxide (narcoanabiosis);

The state of cenoanabiosis of a food product can be achieved as follows:
- by weak salting (halocenoanabiosis);
- by natural acidification, resulting from lactic fermentation (acidocenoanabiosis);
- with alcoholic fermented products (alcoholcenoanabiosis).

The state of abiosis of a food product is obtained by the following means:
a) *mechanical*:
- sterile filtration, using membrane techniques (sestoabiosis);
- storage in an aseptic environment (aseptoabiosis);
b) *physical*:
- pasteurization and thermal sterilization using heat by classical techniques or with the help of infrared radiation, microwaves, ohmic heating, indirect heating with Joule effect etc. (thermoabiosis);
- pasteurization and sterilization with gamma radiation, ultraviolet, accelerated electrons (radioabiosis);
c) *chemical*:
- antiseptic treatments (antiseptoabiosis);
- antibiotic treatments.

Foods preserved on the principles of anabiosis and cenoanabiosis provide limited shelf life, determined by the very action of the preservatives used.

Preservation on the basis of abiosis gives food the longest storage life, theoretically unlimited. However, a number of chemical changes that occur in products or the interactions between the various constituents, lead to a limitation in time of their shelf life.

MATERIAL AND METHOD

The category of modern preservation methods includes thermal and athermal methods. The most important modern athermal preservation methods are:
- *preservation with the help of high pressures*: at pressures of 4000-10000 bar in food there are important changes that inactivate, reduce the activity or stimulate the action of various enzymes, increasing the preservability;
- *preservation by means of the magnetic field*: the static or oscillating magnetic field produces action with lethal effect on some microorganisms, while preserving the sensory and nutritional qualities of the products;
- *preservation by means of ultra-short light pulses*: the pulses generated by a laser or a flash lamp cause the destruction of microorganisms on the inner surface of the package, especially in refrigerated and frozen products, considerably increasing the shelf life or storage time.
- *conservation with the help of the high voltage pulsed electric field*: at a potential of over 1V within the cell membrane, these impulses determine the destruction of the harmful microorganisms, with the preservation of the nutritive principles.

The pulsed electric field (PEF) treatment method is a non-thermal food preservation method that uses electricity for microbial inactivation with minimal negative effects on food quality, electric pulses destroying microbial cell membranes. PEF can be used for pasteurizing liquid foods and pasta products, but also for extracting fruit and vegetable juices.

The membrane of plant cells can be permeabilized by electrical pulses and thus liquids are released easily and completely.

Preserving food with PEF provides products with very good taste and superior nutritional value. Foods treated in this way keep fresh their aroma, taste and appearance.

High voltage electrical pulses (PEF or pulsed electric field) have the highest antimicrobial potential compared to classical techniques, such as cold treatment and pasteurization, thus being able to successfully replace, in whole or in part, classical thermal preservation processes.

During this treatment, the lysis of microbial cells is caused by irreversible structural changes within the membranes, by the formation of pores and the destruction of the semipermeable barrier of the membrane.

Over the last decade, a wide variety of articles and publications have debated this topic, namely: the effect of the high-voltage pulsed electric field on cells and, in particular, on microorganisms.

Under the influence of a short-term electric field (µs) the inactivation of microorganisms takes place, hence resulting the potential of this method of food sterilization. In a cell suspension, an electric field causes a potential difference that crosses the membrane and induces a rapid increase in the conductivity and permeability of the membrane. Membrane destruction occurs when the electrical potential induced within the membranes exceeds a critical value of 1 V, corresponding to an external field, of about 10 kV/cm for E. coli. The increase in membrane permeability and cytoplasmic conductivity, called "dielectric destruction", is explained by the appearance of pores due to the local electromechanical instability of cell membranes. The effects of applying intense electrical pulses (25 kV/cm), from µs to ms (milliseconds) were studied and it was concluded that the application of an excessive potential difference crossing the membrane can lead to irreversible changes in structure, finally leading to the destruction of membrane. Within microorganisms, structural changes due to a potential difference of about 1 V lead to irreversible losses of membrane functions, such as the semipermeable barrier between the cell and its environment.

Promising preliminary results regarding the inactivation of microorganisms within the pulsed electric field have led to increased interest in developing a non-thermal food sterilization process. One of the advantages of using a pulsed electric field over thermal processing methods, which ensures artificial sterilization of food, is the low amount of heat produced. As a result of the small increase in temperature during processing, foods retain their "fresh" physical, chemical and nutritional characteristics and have a satisfactory shelf life when stored in the environment.

The specialty literature mentions that the electrical impulses of high voltage electric fields up to 2 kV inactivate the microorganisms E. coli, Staphylococcus aureus, Micrococcus lysodeikticus, Sarcina lulea, Bacillus subtilis, B. cereus, B. megatherium, Clostridium welichii, Pseudomonas ssp., Saccharomyces cerevisiae and Candida utilis. Electric fields of up to 25 kV/cm were applied in the form of a series of direct current pulses from 2 to 20 µs on the suspension of microorganisms. The inactivation of microorganisms was the result of electrical impulses and was not due to the chemical products of electrolysis or an increase in temperature. The maximum temperature rise was 10 °C for 10 pulses of 20 µs at 19.5 kV. The inactivation of the microbial population was dependent on the strength of the electric field and the duration of the treatment and also was dependent on the concentration and nature of the treated cells, the yeasts being much more sensitive than the vegetative bacteria.

The mechanism by which the intensity of the high voltage electric field inactivates the vegetative bacterial cells in suspension consists in the destruction of the membrane as lysis of protoplasts, leakage of the intracellular content, loss of the ability of E. coli to plasmolize in hypertonic medium (20 mM phosphate buffer, pH 7.2 + 10% sucrose).

Membrane destruction is the direct cause of cellular inactivity. There is a similarity between the number of cells inactivated by a particular treatment and the number of cells capable of forming spheroblasts. Staphylococcus aureus suspensions were first subjected to direct current pulses with a field strength of 25 kV/cm and then treated by enzymatic dissolution of cell walls in a hypertonic medium. The direct relationship between the effects of pulsed treatment on cell inactivity and membrane destruction, as measured by poor or no spheroblast formation, demonstrates that cell inactivation is a result of membrane destruction (Table 1).

Table 1

Staphylococcus aureus activity after pulsed electric field treatment

Electric field [kV/cm]	Survivors [%]	Unlyzed protoplasts [%]
0.00	100.0	100.0
9.25	100.0	100.0
14.25	35.0	43.0
19.50	0.9	16.0
24.00	0.3	3.0
27.50	0.6	1.5

Bacteria and yeasts in liquid suspensions are inactivated by high-voltage pulsed electric fields applied to the liquid. Using high voltage electric fields, up to 25 kV/cm, for short durations (μs), inactivation percentages higher than 99.9% were demonstrated.

RESULTS AND DISCUSSIONS

There are vrious companies that produce equipment based on pulsed electric fields, both for the food and beverage industry and for the scientific sector.

The **Elea company (Germany)**, produces a wide range of equipment (Elea CoolJuice 10, 100, 1000; Elea SmoothCut 10, 100, 1000; Elea SmoothCut ONE; Elea PEFPilot) for the treatment of liquids, viscous products and horticultural products, in pulsed electric field.

The CoolJuice system is intended for the treatment within pulsed electric field (PEF) of liquid or viscous products: juice, smoothies, milk, wine and other liquid consumables, at a much lower temperature than traditional thermal pasteurization.

The CoolJuice system range has processing capacities from 50L to 10,000L per hour. Table 2 presents the technical characteristics of the CoolJuice system (fig.1)

Table 2

Technical characteristics of the CoolJuice system

Electric pulse generator	
Control system	Touch screen, peak voltage and current measurement, oscilloscope connectors, safety lock, emergency stop.
Cooling	Air and water cooling depending on the system
Dimensions	Depending on the system, the stainless steel housing
Continuous flow treatment chamber	
Capacity	Up to 10000 l/h of pumpable products, subject to load ratio and process requirements
Electrodes	Titanium
Necessary utilities	
Power supply	400/415 V, 50 Hz, (3 phase / null). Other options available
Cooling	Air and water cooling depending on the system

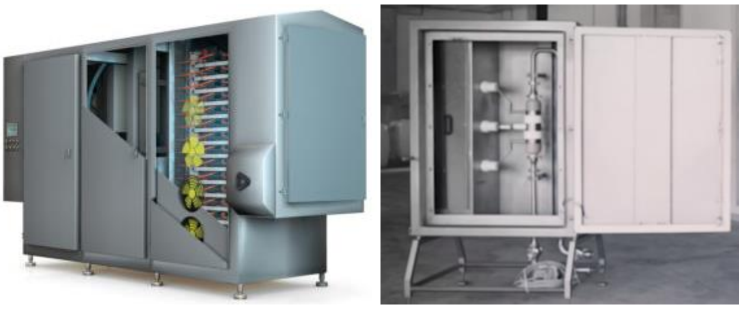

Fig. 1. CoolJuice system

The SmoothCut system, with the treatment belt, is ideal for the treatment of tubers, roots, vegetables and fruits, being produced in four models: 1, 10, 100 and 1000. The treatment of vegetables with PEF at low temperatures, replaces the need to bleach potatoes and other products before cutting. Table 3 shows the characteristics of the SmoothCut system (fig.2)

Table 3

Technical characteristics of the SmoothCut system

Electric pulse generator	
Control system	Touch screen, peak voltage and current measurement, oscilloscope connectors, safety lock, emergency stop.
Cooling	Air and water cooling depending on the system
Dimensions	Depending on the system, the stainless steel housing
Continuous flow treatment belt	
Capacity	Up to 70 t/h of potato in potato-water mixture
Water management	Automatic level control, overflow channel, automatic drain valve, water conductivity and temperature measurement
Electrodes	Stainless steel
Dimensions	Depending on the system, the treatment belt must be attached to the generator
Power supply	Supplied from the generator
Necessary utilities	
Power supply	400/415 V, 50 Hz, (3 phase / null), 100 A. Other options available
Water	Water supply to the treatment belt
Compressed air	6 bar
Drain Valve	DN150 Flange

Fig. 2. SmoothCut system

Table 4 presents the characteristics of the SmoothCut ONE system (fig.3)

Table 4

Technical characteristics of the SmoothCut ONE system

Continuous flow treatment belt & Electric pulse generator	
Capacity	Up to 6 t/h of potato in potato-water mixture
Safety standards	UL, ULc or CE
Water management	Automatic level control, water conductivity and temperature measurement
Electrodes	Titanium
Dimensions	4121 x 1347 x 1599 mm (Lxlxh)
Tank capacity	Approx. 1500 l +/- depending on the working level
System mass	1000 kg – empty
Power supply	Supplied from the generator
Pulse shape	Rectangular pulses with high energy efficiency
Control system	Siemens PLC: remote operation, maintenance and diagnostic option. Touch screen operation. Display processing parameters
Optional	Different types of platforms for system integration in existing installations
Necessary utilities	
Power supply	400/415 V, 50 Hz, (3 phase / null), 32 A. Other options available
Water	Water supply to the treatment belt
Compressed air	6 bar
Drain Valve	DN150 Flange

Fig. 3. SmoothCut ONE system

Table 5 presents the characteristics of the PEFPilot system (fig. 4)

Table 5

Technical characteristics of the PEFPilot system

Electric pulse generator	
Control system	Touch screen, peak voltage and current measurement, oscilloscope connectors, safety lock, emergency stop.
Power supply	220 V, 50 Hz
Cooling	Air cooling
Dimensions	1525 x 955 x 1546 mm (L x l x h), stainless steel housing
Treatment chamber	
Capacity	Up to 10 l
Necessary utilities	
Power supply	230 V, 50 Hz. Other options available

Fig. 4. PEFPilot system

Pulsemaster (USA) provides pulsed electric field (PEF) based systems for both the food and beverage industry and the science sector.

The industrial solution for the treatment of PEFs of solids, semi-solids and liquids is known as *Conditioner*.

Under the brand name *Solidus* there is the pilot plant, with discontinuous operation, which treats solids and semi-solids for research purposes and can be used for micro production.

Under the brand name *Liquidus*, there is a pilot plant, with continuous operation, which treats liquids for research purposes and can be used for small production turnovers.

PEF systems for the food and beverage industry

The average power range of industrial systems with pulsed electric field is up to 100 kW, and the pulses are applied at repetition rates of up to a maximum of 500 pulses per second to allow sufficient treatment of all elements.

For solid product cell disintegration applications, a typical processing line consists of a transport system, a treatment unit, a processing unit and a pulse generating unit. Figure 5 shows the Solidus System.

Fig. 5. Solidus System

For the disintegration of the cells of solid products, such as fruits, vegetables and potatoes, the treatment systems allow processing capacities from 1 to 60 tons per hour. The largest PEF industrial equipment produced by Pulsemaster (150kW), allows processing capacities of up to 90 tons of potatoes per hour. Belt conveyor systems are an optimal solution for treating potato tubers, roots, vegetables and fruits. Figure 6 shows the 150 kW Solidus System.

Fig. 6. 150 kW Solidus System

For easy preservation of beverages and other (semi) liquids, a typical processing line consists of a supply tank, a pump, a processing unit, a pulse generating unit, a chiller (if necessary) and a buffer tank. The capacities of the systems vary from 30 liters to 5000 liters per hour per system. Flow, temperature and energy consumption are constantly measured.

The processing of raw milk, cheese-making milk, yoghurt-based drinks or whey, using pulsed electric field treatment, allows the inactivation of microbial cells, which leads to a prolonged shelf life and the preservation of fresh taste and healthy compounds. PEF technology uses low temperatures to ensure the preservation of freshness and natural nutritional value, obtaining a higher probiotic value. Figure 7 shows the Liquidus System.

Fig. 7. ***Liquidus System***

The technology can be used to treat fresh juices and smoothies. By permeabilizing the cell membranes of microorganisms, the PEF treatment method allows an increase in shelf life, while maintaining the quality and freshness of the product.

Pulsemaster produces a series of systems for scientific and research organizations, adapted to specific research needs. Under the brand name Solidus are produced PEF pilot systems, with discontinuous operation. They can treat solids and liquids for research purposes.

Figure 8 shows a PEF system for scientific and research organizations.

Fig. 8. PEF system for scientific and research organizations

CONCLUSIONS

The pulsed electric field (PEF) treatment method is a non-thermal food preservation method that uses electricity for microbial inactivation with minimal negative effects on food quality.

One of the advantages of using a pulsed electric field over thermal processing methods, which ensures artificial sterilization of food, is the low amount of heat produced. As a result of the small increase in temperature during processing, foods retain their "fresh" physical, chemical and nutritional characteristics and have a satisfactory shelf life when stored in the environment.

Preserving food with the help of PEF offers products with very good taste and superior nutritional value. Foods treated in this way keep their aroma, taste and appearance fresh.

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