

Newer Technique in Food Processing: High Intensity Light, Pulse Electric Field and Infrared

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Abstract – For food processing and preservation demand for minimally processed foods and eco friendliness, various technologies were developed. Preservation is the most important process related to the entire food product. Preservation of food can be achieved by various ways like addition of salt, sugar, preservatives, antioxidants, naturally occurring antimicrobial substances and also by the processes like drying, freezing, refrigerated storage and hurdle technology. Novel technologies like high intensity light (HIL), pulse electric field (PEF) and infrared (IR). The main problem with the traditional thermal processing as pasteurization and sterilization are the golden standard protocols to extend the shelf life of food. However, it is known that heating may cause losses in nutritional, physico-chemical, rheological, and sensory characteristics because certain food components are thermally sensitive. The following review article is made for different non thermal processing methods and mechanism of action of the technology in Food Processing.

Keywords – High Intensity Light (HIL), Pulse Electric Field (PEF), Infrared (IR), Non-Thermal Technologies, Food Processing

I. INTRODUCTION

Consumers are looking for safe and high-quality food products, healthy habits and a balanced diet. However, it is known that fresh fruits and vegetables have been associated with food borne outbreaks. Therefore, food safety is one of the major concerns of the food industry as well as regulatory agencies. Fruits, vegetables, fats, oils, sugars, dairy ingredients, meats, flours and others food materials that are complex mixtures of amino acids, short chain organic acids, vitamins, proteins, lipids, volatile organic compounds, and minerals, need to be decontaminated to extend the shelf life (reduce incidence of microorganisms) and to preserve the natural quality (reduce chemical alterations) before commercialization.

1. Non thermal technologies: Food processing technologies can be classified as thermal and non thermal, depending on the use or not of heat. Some examples of thermal treatments are ohmic heating, microwave, radiofrequency, infrared, and inductive heating; and examples of non thermal treatments are high hydrostatic pressure, pulsed electric fields, high-intensity light, pulsed X-rays, membrane technology, oscillating magnetic fields, ultrasound, ozone, and plasma. Plasma applied for material sterilization was firstly patented in 1968, and

plasma from oxygen was applied in 1989 for surface decontamination with biomedical purposes

2. High intensity pulsed light technology in food processing

Rapid and effective low thermal, low energy purification and sterilization technique by use of very high power and short duration light pulses emitted by inert gas flash lamps. Principle (Ultra-violet-180 to 400 nm, visible light- 400 to 700 nm, Infra-Red-700 to 1100nm) Ultraviolet rays of short wave-length and high energy were used and with total energy being equal power provided by pulses is greater than that provided by continuous.

The mechanism of microbial inactivation by ILP is mainly explained through the photochemical effect, which includes chemical modification and cleavage of DNA, protein denaturation and other alterations of cellular materials, thus preventing cells to replicate. Photo thermal and photo physical effects have been also proposed to explain mechanism of inactivation during the ILP treatment. Pulsed Light Working and Equipment The generation of pulsed light is done by charging the capacitors, which discharge the power as a high-voltage pulse of electricity to lamps filled with inert gas. The electricity goes through the gas into the lamp allowing it

to emit a very strong pulse of light. These rapid pulses of lights (generated at a speed of tens per second) are directed to the surface or packaging of the food. The generation of pulsed light is done by charging the capacitors, which discharge the power as a high-voltage pulse of electricity to lamps filled with inert gas. The electricity goes through the gas into the lamp allowing it to emit a very strong pulse of light. There are ammeters that measure the lamp current treated for 5s for the decontamination of fresh raspberries since it did not damage the quality during the storage. The researchers concluded the pulsed light treatment could be used for decontamination of fresh raspberries. Application of High Intensity light in food processing and preservation

- High Intensity light treatment given to eggs for surface decontamination
- Continuous flow intensity light system for bacterial inactivation in fruit juices and milk
- Decontamination of food powders using pulsed ultraviolet (UV) light
- Pulsed light treatment for decontamination of chicken from food pathogens Pulsed light treatment for freshly cut mushroom

3. Advantages

The intensity of light, that lasts for only a second, is 20,000 times brighter than sunlight, but there is no thermal effect, so quality and nutrient content are retained. The xenon-flash lamps used in pulsed light treatment are more eco-friendly than the mercury vapor lamps used in ultraviolet (UV) treatment. Pulsed white light is not strictly a non-thermal, but the thermal action, due to its very short duration; it doesn't show much adverse effect on the nutrients.

4. Disadvantages

A possible problem of this preservation method is that folds or fissures in the food may protect microbes from being exposed to the pulsed light. There might be some strains of micro-organisms which are resistant to the pulsed light treatment, for example *Listeria monocytogenes*. This technique for decontamination of micro-organisms is useful mostly in case of liquid foods and surface of solid foods and hence limiting its application.

5. IR heating

Food preservation with improving its safety and quality has been a prime goal of food processors. The use of heat through thermal processing operations, such as pasteurization, sterilization, drying and evaporation, is still the preferred method for achieving microbiological safety of food products. Infrared radiation The electromagnetic spectrum has been divided into several

regions from low to high energy. These regions are long radio wave, short radio wave, microwave, infrared (IR), visible, ultraviolet (UV), X rays, and gamma rays. Visible light is actually a very narrow region within the spectrum, ranging from about 380 – 700nm. By contrast the IR region is very large, (700 nm – 1.0 mm) and divided into near-infrared radiation (NIR), mid-infrared radiation (MIR), and far-infrared radiation (FIR) between 0.5 and 1,000 μm . It is transmitted as a wave and gets converted into heat when it impinges on the food surface.

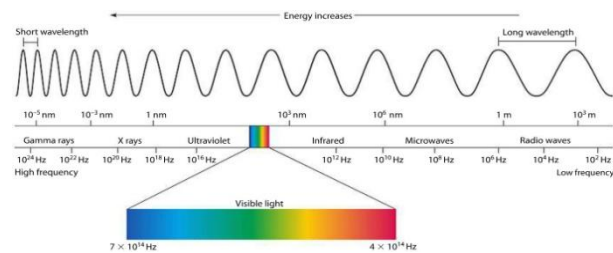


Fig 1. Electromagnetic Spectrum

Principle When IR radiation is used to heat or dry moist materials, the radiation impinges the exposed material, penetrates it, and the energy of radiation converts into heat. The depth of penetration depends on the composition and structure of the fruits and also on the wavelengths of IR radiation. When a material is exposed to the radiation, it is heated intensely and the temperature gradient in the material reduces within a short period. It results in high rate of heat transfer compared to conventional drying and the product is more uniformly heated rendering better quality characteristics. In conventional drying, heat is mainly subjected to the surface of the food by convection from circulating hot air and further transfer of heat to the core takes place by conduction, which results in case hardening of the material and hinders mass transfer.

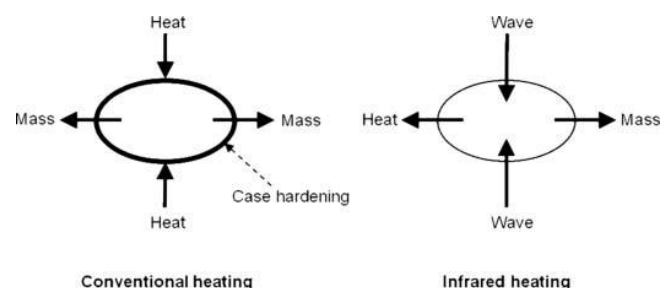


Fig. 2. Schematic Representation of Conventional And Infrared Heating.

Equipment for infrared processing IR heat processing is becoming an important heat treatment in the food industry because of the simplicity of construction and operation of

IR equipment, its fast transient response, significant associated energy savings over other thermal processes, and easy accommodation with convective, conductive, and microwave heating. The main component of IR equipment for heating is the radiator, of which there are various types and shapes. They may be divided into gas heated radiators (long waves) and electrically heated radiators. Lamps were mounted on a construction that could be moved up and down and the distance between radiators and apple slices could be adjusted. Emitted radiation reached a wire tray placed on a balance; hence changes in mass could be recorded continuously. It was designed in such a way that convective or near-IR drying could be done individually or in combination (Figure 3).

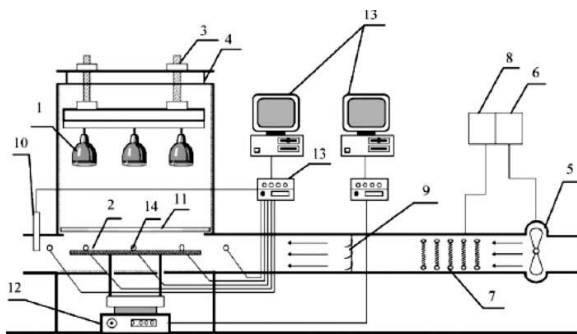


Fig. 3: Laboratory Infrared-Convective Dryer. 1-Glass Lamps, 2-Wire Tray, 3-Distance Adjustment Screws, 4-Drying Chamber, 5-Fan, 6-Fan Output Control, 7-Electric Heater, 8-Electric Heater Control, 9-Air Baffles, 10-Anemometer, 11-Quartz Glass, 12-Balance, 13-Computers, And 14 Thermocouples

II. APPLICATIONS

These include short process time, increased energy efficiency, uniform product temperature, better-quality finished products, high degree of process control parameters, high heat transfer coefficient, space saving, and being environmentally friendly. IR heating has been applied in drying, baking, roasting, blanching, pasteurization, and thawing of food products.

- Processing
- Baking
- Drying
- Microbial Inactivation.
- Thawing
- Roasting
- Blanching.
- Surface Decontamination

Limitations of infrared processing The main effect of IR heating is due to heating of a thin layer of food material on the surface (1). The IR radiation cannot penetrate deep and heats up only a few millimeters below the surface of the sample. The absorbed energy is then transferred by

conduction to other areas within the food material. As the sample volume increases, this conduction is limited, and thus the total energy absorbed is limited. The penetrative radiation energy does not make significant contribution to internal heating. Hence, in order to achieve optimum use of energy the combination of IR heating with microwave or other common conductive and convective modes of heating holds great potential.

1. Pulse Electric Field

Thermal processing is a major technology that has been commonly used in the food industry to increase shelf life and maintain food safety with low processing costs. To qualify as an alternative method, a new technology should have significant impact on quality while at the same time maintain the cost of technology within feasibility limits. In recent years, several technologies have been investigated that have the capability of inactivating microorganisms at lower temperatures than typically used in conventional heat treatments Pulsed electric field (PEF) technology is a non-thermal food preservation method that involves the use of short electricity pulses for microbial inactivation while imposing minimal detrimental influence on food quality (2).

History Pulsed discharges of high voltage electricity across two electrodes for microbial inactivation were first investigated in the 1950th (3,4), resulting in a process called electrohydraulic treatment. The electrodes were submerged in the liquid medium within a pressure vessel, electric arcs were generated by high voltage pulses forming transient pressure shock waves up to 250MPa and ultraviolet light pulses. The application of electric fields for electroporation of apple mash was first reported by Flaumenbaum in which an increase in juice yield of 10–12 per cent was found and the products were described to be lighter in colour and less oxidized than after a heat or enzymatic pre-treatment (5).

Principle The basic principle of the PEF technology is the application of short pulses of high electric fields with duration of microseconds, micro- to milliseconds and intensity in the order of 10-80 kV/cm. The processing time is calculated by multiplying the number of pulses times with effective pulse duration. These electrodes have a specific gap between them which is known as treatment gap of the chamber. During PEF processing, high voltage is applied that results in the inactivation of microorganisms present in the food sample. The electric field is applied in different forms like as exponentially decaying waves, bipolar waves or oscillatory pulses. The process can also be carried at various temperature ranges such as ambient, sub-ambient and above-ambient temperatures (6).

Mechanisms It is generally accepted that the primary effect of PEF on biological cells is related to local

structural changes and the breakdown of the cell membrane, which is a highly important component of the biological cell as it acts as a semi-permeable barrier responsible for mass transfer and plays an important role in the synthesis of RNA and DNA, protein and cell wall components as well as many other complex metabolic activities (7). Disruption of intracellular organelles and other structural changes have also been described (8). When the overall potential exceeds a critical value of about 1V, depending upon the compressibility, the permittivity and the initial thickness of the membrane (9), the electrocompressive force causes a local dielectric rupture of the membrane inducing the formation of a pore, acting as a conductive channel (10).

Taking into account a membrane thickness of 5 nm, this translates to a dielectric strength of 2000 V/cm. A drastic increase in permeability re-establishes the equilibrium of the electrochemical and electric potential differences of the cell plasma and the extracellular medium. Alternative concepts are based on molecular reorientation and localized defects within the cell membrane which are expanded and destabilized by exposure to an electric field. The presence of small fluctuating hydrophobic pores in the lipid matrix was suggested to be the initial structural basis of electroporation. PEF Systems PEF treatment systems are composed of PEF treatment chambers, a pulse generator, a fluid-handling system, and monitoring systems.

1. Treatment Chambers PEF treatment occurs inside of a PEF treatment chamber, which houses electrodes and delivers a high voltage to a food material. Various types of PEF treatment chambers have been used for PEF treatments. A uniform distribution of electric field strength in PEF treatment chambers is desirable to ensure that each microbial cell within a population receives the same PEF treatment. The uniform distribution of electric-field strength also simplifies mathematical models, which predict microbial inhibition by PEF (11). Treatment chamber design has improved from static treatment chambers to continuous treatment chambers.

2. Static Treatment Chambers: Static treatment chambers are mostly preferred in laboratory-scale experiments.

3. Continuous Treatment Chambers: A continuous treatment chamber was initially invented by Dunn and Pearlman. The chamber consisted of two parallel-plate electrodes and a dielectric spacer insulator. The electrodes were separated from food by conductive membranes made of sulfonated polystyrene and acrylic acid copolymers. Coaxial and the cofield PEF treatment chambers are currently widely used due to their simplicity in structure (12,13,14). Electrical current flows perpendicularly to food flow in coaxial PEF treatment chambers and in parallel to food flow in cofield flow PEF treatment chambers. A cofield flow tubular PEF treatment

chamber used in commercial scale. The chamber consisted of two boron carbide tubular electrodes and a tubular ceramic insulator body. The chamber had an inner diameter of 0.808 cm in the cylindrical treatment zone and a distance of 1.270 cm between the electrodes. This PEF treatment chamber could be connected up to eight in parallel for electrical flow and in series for fluid flow for the commercial-scale PEF system.

4. Pulse Generator Pulse generators convert low voltage into high voltage and provide the high voltage to PEF chambers. Square, exponential decay, or oscillatory pulses are generally used for PEF treatment. A low-level voltage is collected and stored in a capacitor.

Stored voltage at a high level is discharged instantaneously. Generation of a high-voltage PEF within a food in a treatment chamber requires a large flux of electrical current through the food for microseconds. Due to a very short period of discharge time (i.e., microseconds), heating of the foods is minimized. The laboratory-scale PEF system and a later model of pilot plant-scale PEF systems were based on a patented design using semiconductor H-bridge switches coupled with an output pulse transformer.

The rated voltage for the laboratory systems is 15 kV and for the pilot systems is 35 kV, both with bipolar square wave pulse shape. The commercial-scale pulse generator provided bipolar square waveform pulses with a maximum peak voltage of ± 60 kV and a maximum peak current of 600 A into multiple PEF chambers during PEF processing. The 60-kV power supplies charged storage capacitors that were partially discharged by a series of solid-state switches to form square wave bipolar pulses. The maximum repetition rate of the pulse generator was 2000 pps.

5. Fluid-Handling System The basis of fluid-handling systems is to transfer products for processing and packaging. Fluid-handling systems also monitor and control flow rate, temperature, and pressure during processing. For bench top-scale PEF units, the fluid-handling system is generally formed by stainless steel tubing and a pump, providing continuous flow of a product to be treated. For pilot plant- or commercial-scale PEF systems that are integrated with aseptic packaging system, the fluid-handling system must have mobility and flexibility of processing sequence and allow system cleaning and sterilization (e.g., cleaning-in-place and sterilization-in-place).

6. Temperature and Pulse-Monitoring Systems Bench top-scale PEF systems usually have thermocouples (e.g., K type) connected to stainless steel tubes, in which food product flows, to monitor temperature changes during PEF treatments. Temperatures of products before and after the treatment are controlled by placing the tubes in

water baths set at target temperatures. Pilot plant- or commercial-scale PEF systems employ a set of tubular heat exchangers for temperature control before and after PEF treatments.

Working PEF technology is based on a pulsing power delivered to the product placed between a set of electrodes confining the treatment gap of the PEF chamber. The equipment consists of a high voltage pulse generator and a treatment chamber with a suitable fluid handling system and necessary monitoring and controlling devices. Food product is placed in the treatment chamber, either in a static or continuous design, where two electrodes are connected together with a nonconductive material to avoid electrical flow from one to the other.

Generated high voltage electrical pulses are applied to the electrodes. The food product experiences a force per unit charge, the so-called electrical field, which is responsible for the irreversible cell membrane breakdown in microorganisms. This leads to dielectric breakdown of the microbial cell membranes and to interaction with the charged molecules of food. Hence, PEF technology has been suggested for the pasteurization of foods such as juices, milk, yogurt, soups etc.

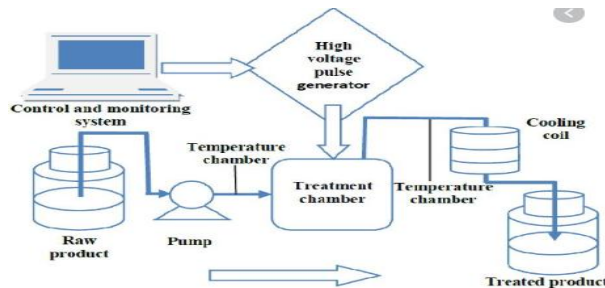


Fig.4: Pulse Electric Field in Food Processing

2. Advantages

- Less treatment time.
- Less treatment temperature.
- Kills vegetative cells.
- Colors, flavors and nutrients are preserved.
- No evidence of toxicity.
- Decontamination of heat sensitive foods.
- Best suitable for liquid foods.
- Increase shelf life and maintain food safety with low processing costs.
- Pasteurization of fruit juices, soups, liquid egg and milk; no environmental hazard.

3. Disadvantages

- High initial cost.
- No effect on enzymes and spores.
- PEF alone; only suitable for liquids particles in liquids.

- Products of electrolysis may adversely affect foods.
- PEF treatment is effective for the inactivation of vegetative bacteria only.
- Energy efficiency not yet certain, the presence of bubbles, which may lead to non-uniform treatment as well as operational and safety problems.
- Limited application, which is restricted to food products that can withstand high electric fields.
- Refrigeration is required to extend the shelf life.

II. APPLICATION IN FOOD PROCESSING AND PRESERVATION

Pulsed electric field (PEF) is another non-thermal technology that can be used to inactivate bacterial cells at ambient temperatures. The process involves placing the food material between two electrodes and passing pulses of high electric field (1-50 kV/cm) strengths. Since the pulses are applied for short durations (2 μ s to 1 ms) the negative impact on food quality due to heat processing is highly diminished.

1. Applications in food industry-

Application of PEF technology has been extensively demonstrated for the pasteurization of various food products like juices, milk & dairy products, soup and liquid eggs. However, it has several limitations such as product must be free from air bubbles and must have lower electrical conductivity. Additionally, particle size should be less than the gap of the treatment region to ensure appropriate treatment. PEF is generally not suitable for solid foods however several solid products have also been investigated to be efficiently treated by deploying PEF treatment. PEF technology can also be used to enhance the extraction of several bioactive components and sugars from plant cells.

PEF processing has shown its potential to treat less viscous fruit juices having less electrical conductivity such as apple, citrus and cranberry juices. PEF technology also executes beneficial aspects on the quality parameters of fruit juice. Correspondingly, (15) compared pasteurized and PEF-treated citrus juice during refrigerated storage (4°C) for a period of 112 days and observed less browning in PEF-processed juice comparatively to traditionally pasteurized juice due to conversion of ascorbic acid to furfural. In recent years, PEF technology has been utilized for various purposes like enhancement of drying efficiency, modification of enzymatic activity, solid food preservation, waste water treatment and extraction (16).

2. Inactivation of Microorganisms PEF treatment has lethal effects on various vegetative bacteria, mold, and yeast. Efficacy of spore inactivation by PEF in combination with heat or other hurdles is a subject of

current research. A series of short, high-voltage pulses breaks the cell membranes of vegetative microorganisms in liquid media by expanding existing pores (electroporation) or creating new ones. Pore formation is reversible or irreversible depending on factors such as the electric field intensity, the pulse duration, and number of pulses. The membranes of PEF-treated cells become permeable to small molecules; permeation causes swelling and eventual rupture of the cell membrane. Raw and reconstituted apple juice, peach juice, skim milk, beaten eggs, and pea soup exposed to PEFs of 25–45 kV/cm were treated using the chamber designed at Washington State University. *E. coli* inoculated in skim milk and exposed to 60 pulses of 2s width at 45 kV/cm and 35°C was reduced by 2D (12).

3. PEF in fruit Processing - PEF processing has promising applications in citrus industry with special reference to the inactivation of microorganisms and prevention of developing off-flavors during the storage (17). For instance, pectin is a very useful component found in many fruits that is traditionally being extracted through enzymatic reaction but this reaction has less yield of pectin due to poor efficiency. Alternatively, PEF treatment is employed as short pulses to avoid excessive heat and undesirable electrolytic reactions that can enhance the extraction rate of pectin from fruit pomace (12).

4. Bacterial inactivation in milk by PEF- Inadequately pasteurized milk may cause several health hazards due to the presence of several spoilage causing and pathogenic bacteria particularly *Escherichia coli* and *Listeria* and *Pseudomonas* spp. PEF-induced microbial inactivation is believed to be an effective way of milk preservation without adversely affecting the milk quality. The inactivation of *E. coli* varied as a function of the electric field intensity, number of pulses, and pH. Low-field intensity (20 kV/cm) resulted in insignificant inactivation of microorganisms independent of temperature and pH ($p > 0.05$).

5. PEF and meat quality - Meat products have been widely consumed around the globe due to the presence of valuable micronutrients high quality protein. Quality of meat is at prime importance because meat quality is considered as the most vital factor for purchasing decisions of consumers (18). Pulsed electric field technology has shown its potential for various applications in solid foods with different aims including structural modifications, changing physical quality parameters, extraction of bioactive compounds and preservation (12).

6. Consumer acceptance of PEF treated products - Pulsed electric field technology is gaining importance as a non-thermal way to process or preserve foods. Conversely, there is a lack of steadiness in terms of

terminology, product & process description, product communication with consumer and marketability of the PEF-processed foods. Efficient marketability of an emerging technology needs unambiguous benefits for consumers. Consumer attitude determines the level of acceptance of a novel food product and this attitude depends on the method of introduction of a new product and technology (19).

IV. CONCLUSION

Food processing technologies have come a long way in terms of time and energy savings, extended retail shelf life and ready-to-use products. However, the implementation of such technologies in industrial food production is still rather limited. There are several roadblocks to implementing food processing technologies. The main ones are low consumer acceptance or rejection, non-open market access, and lack of knowledge and information among food producers on how to integrate such technologies. Furthermore, an applicable validation system is missing that will integrate these technologies one by one based on a generalized approach.

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