Emerging Technologies: High- Intensity Pulsed Electric Fields (PEF)

Pulse – a single disturbance that moves through a medium from one point to the next point
Energy is what is transmitted from point A to B. medium doesn't travel between two places.

PEF: Short electric pulses used to preserve foods

- Non-thermal processing of foods
  - Short treatment time (typically below 1 second) – depends on bug we are removing
  - Reduced heating effect – short treatment – won't cause drastic changes in food
  - Energy lost during heating food is minimized
  - Results in fresh like food characteristics of food and high sensorial quality and nutrient content.
  - NOW: Preserving liquid and semi-liquid foods (milk, soup, juice) as liquids conduct electricity better than solids (just removing bugs)
  - FUTURE: Removing micro-organisms and producing functional constituents (where technology is heading)

PEF effectiveness affected by..

- The physical properties of food (liquid content)
- Electrical conductivity
- Density
- Specific heat – time taken to heat up.
- Viscosity

PEF Process determined by

- The field strength – strength of electric current
- Treatment time – how many volts is pushed through and for how long.

PEF vs Thermal Pasteurization

- PEF is much more energy efficient, less energy required to get to a heated state. Much more energy efficient in a continuous system. Don't want to heat up as it changes the nutritional profile, fresh flavour characteristics and sensory properties.

Basic Principles

- Keep food below temperatures normally used in thermal processing – ideally ambient
- Application of short pulses of high electric fields (up to 400kHz)
  - In between 2 electrodes (uniform treatment to foods), high voltage (20-89 kV/cm), short duration (<1sec), ambient/sub-ambient/slightly above ambient temperature.

Product becomes part of 'electrical circuit' (food in between 2 electrodes) and results in dielectric[1] breakdown of the microbial cell membrane + interaction with charged molecules of food = longer shelf life and improved quality.

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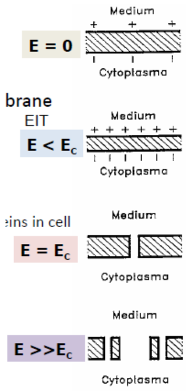
[1] Dielectric material is an electrical insulator that can be polarized by an applied electric field

- Currently used in smaller production lines due to the price of technology until more people take it on board. At the moment can put through 500L/hr.



Technological Aspects

- Generation of high electric field intensifies
- Design of treatment chambers – uniform treatment/ minimum increase in temperature.
    - Temp generated in one part of product- burnt tasting food, microbes not inactivated
    - Shelf life decreased – minimize increase in temperatures.
- Design of electrodes that minimizes effect of electrolysis[2]
    - Current is applied→ ions migrate towards the oppositely charged electrodes
    - They give up their charge→ become uncharged atoms or groups
    - Liberated or deposited at the electrode/ react chemically with the electrode, solvent or each other.
    - Breakdown.
- High field intensities are achieved by storing a large amount of energy in a series of capacitors (bank) for a DC power supply
- Discharged as the high voltage pulses

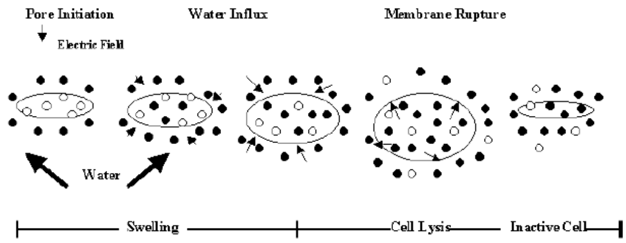
Mode of action on microorganisms; breakdown of bug/cell

1. Cell membrane of microorganism: apply electric current on medium, cell membrane swells and becomes more permeable to charge trying to get through.

2a. Either breakdown or compression

2b. Electroporation: viscoelastic properties of membranes change, fluid mosaic arrangement of lipids and proteins in cell membrane change configuration, pores form and an electric current can pass through membrane to inside of cell (structural defects in cell membrane). Anything in the cytoplasm scapes out, life force drained out and bug dies. Cell wall splits further (colloidal osmotic swelling) and eventually leads to cell disruption.

Electroporation - colloidal osmotic swelling



<u>Factors affecting microbial inactivation</u>: different bacteria respond differently to electrical currents

1. Process Electric field intensity, pulse width (fat/skinny), treatment time, temperature, pulse waveform (static, regular beat through product or is longer/shorter)

Electric field intensity

- increase in the electric field intensity (E), above the critical transmembrane potential (Vc) ie. electroporation theory
- Critical electric field intensity below which inactivation doesn't occur (Ec) increases with the transmembrane potential of the cell. – larger cells have ↑ transmembrane potentials, larger Ec requires a greater field.
- Pulse width – increasing the number of pulses, decreases the electric field intensity required to achieve the same kill. Fast pulses- decrease voltage needed. Higher voltage – could cause sensorial changes to product. KNOW YOUR PRODUCT, CONSTITUENTS, PH, MICROBES, AGE OF PRODUCT, SUGAR/SALT.

Treatment time

[2] Electrolysis is the chemical breakdown of substance into electrically charged ions because of electric current

- Treatment time = number of pulses x the pulse duration (pulse width)
    - Increase in either of these variables = increased treatment time → microbial inactivation
- Pulse width influences microbial reduction by affecting Ec
    - Longer widths decrease Ec, results in higher inactivation
    - Increase in pulse duration – undesirable temp increase in product
- In certain cases, the number of pulses increasing inactivation can reach saturation
    - Over 10 pulses nothing will happen (saturation), increase voltage.
- Critical treatment time also depends on the electric field intensity applied.
    - Above the Ec, the CTT decreases with higher electric fields
- Processing conditions should be established to give the highest inactivation rate with the lowest heating effect.

Types of pulses
- Exponentially decaying – unidirectional
- Square wave – very lethal and more efficient. Holds high electrical current
- Bipolar or oscillatory pulses "(least effective)

Temperature
- Treatment temperatures and process temperatures impact microbial survival and recovery
    - Treatments at moderate temperature (50-60deg) have been shown to exhibit synergistic effects on microbial inactivation (hurdle technology)
    - At constant E, inactivation increases with temperature increases.
- Application of an electric field does cause some increase in the temperature of the food = proper cooling may be necessary to maintain food temps < thermal pasteurization temps.

2. Microbial: Type, conc. , stage of growth (baby not f.developed, still growing, ↑ susceptibility

Type and number of micro organisms
- Resistance gram positive > gram negative
    - Yeasts have a higher sensitivity than bacteria due to their larger size, however at low electric fields they seem to be more resistant than gram negative cells.
- The number of microorganisms in food may have an effect on their inactivation with electric fields. Mixed results / mechanisms not fully understood.
- Sensitivity: log phase > lag and stationary phase cells
    - Log phase: high proportion of cells undergoing division = cell membrane more susceptible to the applied electric field
    - The killing effect of PEF in the log phase is 30% greater > stationary phase of growth

3. Product: factors that affect process and microbial inactivation include.
pH, antimicrobials, ionic compounds, conductivity (variable in PEF- inverse of resistivity), medium ionic strength, density, viscosity, specific heat.

Electrical Conductivity
- Is the inverse of resistivity – the ability to conduct an electric current
- Liquid foods contain various ions – carry an electrical charge → able to conduct electricity.
- Foods that need a larger electrical conductivity = generate smaller peak electric fields across the treatment chamber – not suitable for PEF treatment.
- Liquid foods > solid foods
    - Decrease in resistance = increase in conductivity = reduce the pulse width = decrease the rate of inactivation.

pH

- The amount of microbes that survive in an acidic condition is less than those in a more basic solution as number of pulses increase.

Viscosity

- Product viscosity determines flow characteristics – affects the uniformity of the process
- A uniform velocity profile during PEF treatment = more uniform process
  - The product velocity profile is more uniform during turbulent flow than in laminar flow
  - Product flow characteristics are determined by the Reynolds number, >2100 indicative of turbulent flow.
  - Increase in Reynolds number is directly proportional to decrease in viscosity. – viscosity affects the uniformity of the electrical current passing through.

Inactivation of spores

- Most studies report that spores are resistant to PEF treatments, only after germination do they become sensitive to PEF. Combined technologies may be required to kill spores.

Effect on enzymes

- Enzymes and food proteins are much more resistant to PEF than vegetative microbial cells.
- Degree of inactivation varied greatly 30-90%, some showed enhanced activity (pepsin)
- Requires a large amount of electrical energy and cooling energy needed
- Additional preservation technologies are required to extend shelf life.

PEF Limitations

- Inactivation of spores, non-homogenous foods, air entrapped in foods, high conductivity foods, availability of commercial equipment, cost, validation of process (ongoing issue and subject of much research), regulatory acceptance.

Food Applications

- Mainly for preservation means, improve the shelf life of (milk, OJ, liquid eggs), enhance the fermentation properties of brewers yeast. Favours high acid liquid foods
- Potential applications = beyond pasteurisation, hurdle for new milk tech.

Electroporation

- Protein channels, pores and pumps are sensitive to electric fields and become initiation sites for electropores
- Cell exposed to high voltage electric field pulses temporarily destabilizes the lipid bilayer and proteins of cell membranes – plasma membranes of cells become permeable to small molecules after being exposed to an electric field.

Inactivation - electrical conductivity

- Increase in the difference between the conductivity of a medium and the microbial cytoplasm = membrane structure weakened
  - due to an increased flow of ionic substance across the membrane
  - → Liquids > solids : Low conductivity = increased inactivation rate of microorganisms even with an application of equal input energy
- Increase in ionic strength of a food = increased conductivity

→ = decrease in the microbial inactivation rate

- Increase in electrical conductivity = directly proportional increase in overall ΔT and energy input during processing at any given dosage
- Acidic pH may enhance microbial inactivation (microbe dependent)
  - effect related to ability to maintain cytoplasm pH near neutrality