Alternative Technologies in Food Processing

Outline

• Thermal methods
  – IR, microwave, RF, ohmic

• Non-thermal methods
  – High pressure, ultrasoincs, membranes, pulsed light, pulsed electric field, irradiation, UV, ozone

• Advantages and applications of alternative technologies

Thermal Methods

• Infrared radiation (0.76 - 350 μm)

• Microwave radiation
  – 915 MHz or 2450 MHz; 12.3 or 32.8 cm

• Radio frequency (RF) radiation
  – 13.56, 27.12 or 40.68 MHz; 7.4 - 22.1 m

• Ohmic heating
Non-Thermal Methods

- High pressure (100 - 800 MPa)
- Ultrasonic waves (>20,000 Hz; 1.7 cm)
- Membrane processing
- Pulsed light (200 nm - 1 mm)
- Pulsed electric field (0.5 - 40 kV/cm)
- Irradiation (Doses < 10 kGy)
- Ultraviolet radiation (200 - 380 nm)
- Ozone (gas or ozonated water)

Electromagnetic Waves

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Application</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELF</td>
<td>0 - 3 x 10^3 Hz</td>
<td>Mains</td>
</tr>
<tr>
<td>Radio frequency</td>
<td>3 x 10^3 - 3 x 10^8 Hz</td>
<td>AM, FM</td>
</tr>
<tr>
<td>Microwave</td>
<td>3 x 10^8 - 3 x 10^11 Hz</td>
<td>TV, Radar</td>
</tr>
<tr>
<td>Infrared</td>
<td>3 x 10^11 - 4 x 10^14 Hz</td>
<td>Laser</td>
</tr>
<tr>
<td>Visible</td>
<td>4 x 10^14 - 7 x 10^14 Hz</td>
<td></td>
</tr>
<tr>
<td>UV</td>
<td>7 x 10^14 - 3 x 10^16 Hz</td>
<td>Lamps</td>
</tr>
<tr>
<td>X-rays</td>
<td>3 x 10^16 - 3 x 10^19 Hz</td>
<td></td>
</tr>
<tr>
<td>Gamma rays</td>
<td>3 x 10^19 - 3 x 10^20 Hz</td>
<td></td>
</tr>
</tbody>
</table>

Infrared Radiation
Infrared Radiation

- Herschel (1800): Placed thermometer in solar spectrum resolved by prism – Heating effect
- IR cooker: 650 - 900 °C; Distance from food
- Tungsten quartz lamps
  - Helically wound tungsten wire in a quartz tube ~3/8” dia.
  - Length: 1-38”; at intervals of ~ 1”; wire supported by tantalum discs to prevent filament from contacting tube
  - Lamp is evacuated and filled with argon
  - Clean, efficient source (~85 % energy conversion to heat)
- IR lamps: Rich red color to foods (buffet lines)

- Absorbed by organic materials at discrete frequencies
  - Corresponds to intra-molecular transitions between energy levels
  - Transitions -- Rotational, vibrational (stretching) movements
- Infrared spectroscopy: Infrared absorption bands of different food constituents are different
  - O-H -- Water (2.7 - 3.3 μm), C = O -- Fats (5.71 - 5.76 μm)
- Instantaneous heating unlike convection ovens
  - Do not need hot air to convey the heat
- Ground beef patties; pest control of seeds, peas
- Effect on humans -- Mainly skin and eyes

Microwave Radiation

- Magnetron (tube with magnetic and electric field perpendicular), circulator, applicator
- Turntable or wave-stirrer for uniformity
- 915 MHz, 2450 MHz
- Dielectric constant (ε’) and loss factor (ε”)
- For most foods, ε’ dec. and ε” inc. with increase in temperature (runaway heating)
- Volumetric heating
- Non-uniform temperature distribution
Microwave Radiation

- If $d_{\text{smallest}} > d_p$, then surface heating occurs
- Polar molecules
  - Atoms tend to borrow electrons from one another
- Dielectric prop. change during phase change
  - Gelatinization of starch is a plateau in “loss” value
  - Denaturation of ham muscle protein is also a plateau
  - Egg white (low salt) shows opposite effect during denaturation
- Viscosity does not generally affect $\varepsilon'$, $\varepsilon''$
  - Viscosity is a large scale effect, while $\varepsilon'$, $\varepsilon''$ are mobility on a small scale

Microwave Radiation (at NCSU)

Continuous Flow Microwave (Institutional Level Package)

- Pipeline in heating section: Ceramic-Plastic combo (to withstand heat and pressure)
  - Optional: Add static mixers between heaters to equalize temperatures
Continuous Flow Microwave: 100 kW (Diced Tomatoes)

- Dicing
- Feeding & Pumping
- Package
- Processing and Packaging
- Color Analysis

Radio Frequency Radiation

- Reverse polarity of electrodes at RF
- 13.56 MHz, 27.12 MHz or 40.68 MHz
- Uniform heating within a high moisture product
- Drying of heat sensitive products
  - Timber industry (glued joints), textile industry (fabrics)
- Post-bake drying of cookies
- Application to particulate foods
Ohmic Heating

- 7 electrode housing machined from PTFE, encased in SS; electrodes connected by SS spacer tubes
- Column mounted vertically; upward flow of product
- Convert to 3,300 Volts per phase by a transformer
- Lack of inert electrode materials, suitable controls
- Electrical conductivity, voltage, C.S. area, inter-electrode spacing, specific heat, particle conc.

Ohmic Heating

- Field distorted around mls. of low conductivity
  - Causes localized hot and cold spots
- Linear relation btwn. temp. and conductivity
- Simultaneous heating of liquid & solids (1-2°/s)
- Pasteurization of milk as early as in the 1920’s
- Problems: product reformulation, runaway heating
- Liquid whole eggs, tomato sauces
High Pressure

- Used for meat processing as early as 1819
- Piston-type compressor generates pressure
  - 100 - 1200 MPa (water or liquid food is the pr. transfer medium)
- Does not cause changes in covalent bonds in foods
- Improved food structure: Gelling proteins, starches
  - Preserves low mol. wt. carriers -- vitamins, flavor components
- Protein denaturation, gelatinization of polysaccharides
- Enzymes such as PPO are pressure-resistant
- Ineffective with C. botulinum (heat resistant)
**High Pressure**

- HP damaged vegetative cells could repair themselves under favorable conditions
  – ~ 60 days at refrigerated temperatures
- Fruit juices, fruits for yogurts, jams, jellies, wine, salad dressing, pre- and post-rigor meat
- Guacamole -- only L.A. refriger. product in U.S.
- Challenge of in-container operation
  – Package must withstand up to 15% compression
- Challenges for semi-continuous operation
  – Seals, valves, pumps, piping

**High Pressure Processing Equipment**

[Video]

**Ultrasonic Waves**
**Ultrasonic Waves**

- Irreversible lethal effect due to cavitation (5500 °C, 50 MPa)
- Compressions & rarefactions: Bubbles
- More effective under high pressure
- Pressure: Intensity of cavitation or number of cavitations increase
- Composition, structure, dimensions
- Velocity, attenuation, acoustic impedance
- *Yersinia enterocolitica, Bacillus subtilis*

---

**Membrane Processing**

- Main application: Purification of blood, water
- Reduction of bacterial content (Microfiltration)
  - Cross-flow: Better Performance, Longer Life
- Low alcohol content beer (Reverse Osmosis)
- Production of whey protein concentrate (Ultrafiltration)
- Concentration of liquid foods (Nano, Reverse)
- Demineralization (Electrodialysis)
- Aroma recovery (Pervaporation)
- *Lysteria, Staphylococcus*
Membrane Processing

• Characteristics to consider
  – Type & loading of microorganisms, viscosity, solids content, fat, protein, salt content, surfactants, polysaccharides, fiber, oxidized compounds, pH

• Important membrane characteristics
  – Selectivity, flux, surface characteristics
  – Thermal, mechanical, chemical stability

• Interesting products
  – WPC, Lactoferrin, Lactoperoxidase
  – α-Lactoglobulin, β-Lactalbumin, κ Glycomacropeptide

Pulsed Light

• Light flashes (170 nm - 2600 nm): 1 - 20 per sec.
  – Range from infrared to UV
  – Emission of broadband white light
  – 0.01 - 50 J/cm²

• Intensity is ~ 20,000 times that of sunlight at surface of Earth

• Duration: 200 - 300 microseconds

• Electrical ionization of a Xenon gas lamp
Pulsed Light

- Non-ionizing; can not penetrate opaque materials
- Inactivates fungi, bacterial spores
- Waste-water treatment
- Surface of fruits, vegetables, meat, poultry, fish, free flowing particulates, baked foods
Pulsed Electric Field

- High electric field (0.5 - 50 kV/cm)
  - 1 - 100 pulses
  - 1-5 Hz
  - Few micro-seconds to milli seconds
- Pioneering work as early as 1960’s
- Parallel plate or coaxial configuration
  - Chamber: Two electrochemically inert electrodes
  - Product flows between these electrodes
- Microbial destruction
  - First order reaction w.r.t. electric field strength

Pulsed Electric Field

- Exponential decay, square wave form pulses
- Square wave
  - More energy efficient
  - Less increase in product temperature
- Microbial destruction by electroporation
  - Rupture theory of Zimmermann
  - External field induces additional transmembrane potential
  - When overall potential > 1 V, rupture takes place
- Liquid whole eggs, apple juice, milk, soup
- *E. coli, Staphylococcus, Pseudomonas*

Irradiation
Irradiation

Gamma Irradiator

http://www.isomedix.com/services/gamma-irradiation/

Electron Beam Facility

http://www.meatandpoultryonline.com/doc/agip-over-eggs-industry-beams-over-irradiation-0001
Irradiation

- Gamma rays -- Co-60, Cs-137 (1- 2 Mev)
  - Photoelectric effect (photon of low energy -- ~ 60 keV)
  - Compton effect (photon of high energy -- ~ 1 meV)
- High energy electrons: van de Graaff generator
- Collision of electrons with Tungsten => X-rays
- X-rays, Gamma rays are photons
  - For food irradiation, both are considered to be the same
  - Photons have higher depth of penetration than electrons
  - Absorbed dose of photons dec. exponentially with depth

Irradiation

- Label and use the “Radura” symbol
  - Petals (food), central circle (irradiation source), broken circle (rays from the energy source)
  - Do not irradiate again (wholesale level)
- Minimize free radicals (vacuum pack, freeze)
- Irradiated milk: Red Cross (prisoners in Europe during WW-II -- 1942; Research began in 1895
- Inhibit sprouting, delay ripening
- *Salmonella, Trichinella, E. Coli* O157:H7
- Detection: ESR, NIR, DNA, half-embryo test

Ultraviolet Radiation
Ultraviolet Radiation

- Carbon-arc lamp or quartz mercury vapor lamp
  - UV-A (320-400 nm), UV-B (280-320 nm), UV-C (< 280 nm)
- Can harm eyes, skin
- Milk has been marketed as improved Vit. D
- UV spectroscopy -- color measurement
- Post-harvest enhancement of color of apples
- Atmospheric bacterial destruction: Storage
- Surface decontamination -- packages, meats

Ozone

- Fifth in thermodynamic oxidation potential
  - Fluorine, chlorine trifluoride, atomic oxygen, hydroxyl free radical
- Declared as GRAS by FDA (very short half-life)
- Corona discharge, photochemical, thermal, electrolytic, chemonuclear
- Advanced oxidation process (increase reactivity)
- Decontamination of fruits, vegetables, carcasses
- Used along with UV-C, hydrogen peroxide, heat
Ozone

- Ozonated ice: Extending shelf-life of fresh fish
- Sanitation of equipment
  - Molds, yeasts, bacteria
- Package sterilization
  - Adhesion
  - BATH and HIC tests for cellular hydrophobicity
- New tech.: Ozone upto 14 % concentration
- Nascent Oxygen burning through bacterial cells
  - S. aureus, B. stearothermophilus, B. cereus

Advantages of these Technologies

- Heat sensitive products
- Better product quality
- New line of products
- Convenience and automation
- Higher throughput
- Selectivity of heating (type of material or location of heating)
- Lower cost

Application of Technology

- Mechanism
  - Stand-alone
  - Combination
- Time factor
  - Scale-up
  - Need to establish health-effects
  - Development of database for approval by regulatory agencies
Concluding Remarks

• Application of technology
  – Stand-alone
  – Combination
• Time factor
  – Scale-up
  – Need to establish health-effects
  – Development of database for approval by regulatory agencies