Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Canada

Adapting High Hydrostatic Pressure for Food Processing Operations

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Objectives

The Latest Developments in HPP Research, Equipment and Applications

1. Review principles and benefits of HPP
2. Discuss pressure effects at various pressurization and temperature levels
3. Examine the developments made in HPP processing and most recent applications
4. Review existing HPP commercial equipment and critical things to consider
5. Existing regulations

Processed Foods

Pros

- Food Cost are declining
- Time management
  - Shopping
  - Preparation and Cooking
- Healthier Foods
  - Fortification (iodine, vitamin D etc)
- Convenience
- Safe

Cons

- Over processed
- High content of sugar, salt, fat
- Chemical preservatives
- Chemical migration from packaging
- Negative impact on health
- Increase calories
- Cause obesity

4 Traditional Processing Concepts

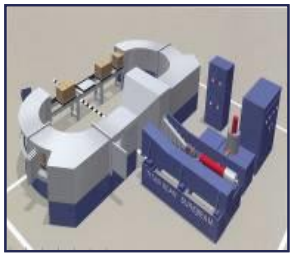
1	Application of thermal energy to elevate product temperatures	
2	Removal of thermal energy to reduce product temperature	
3	Removal of water from products structure	
4	Packaging or the step required to maintain product properties achieved during processing	

ARE THERE NEW PROCESSING TECHNOLOGIES TO MAKE PROCESSED FOODS HEALTHIER and SAFER ?

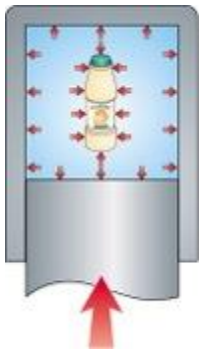
CHALLENGE

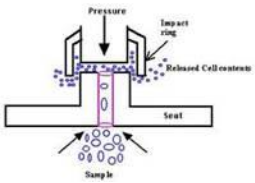
31 Novel Processing Options

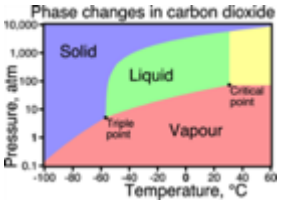
- Electromagnetic energy - 7
- Electrical energy – 5
- Pressure - 6
- Sonication – 3
- Mechanical energy - 3
- Chemical – 5
- Plasma, magnetic field -2



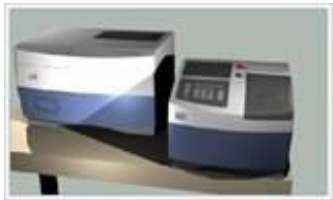
Pressure based technologies

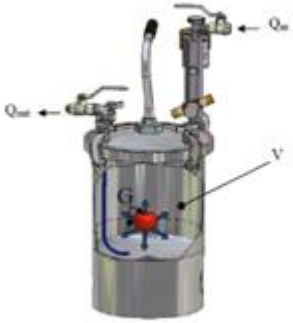






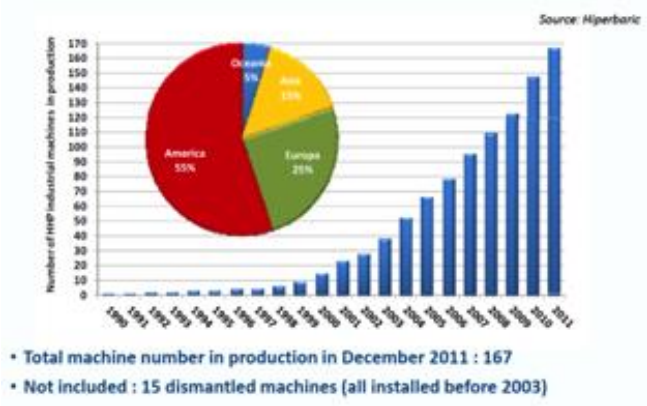
Hydrostatic (HHP)	Pre-Packed Foods	2000 MPa
Hydrodynamic (HDP)	Raw Meats	100 MPa
Hydrodynamic Homogenization (HDH)	Beverages	300 MPa
Pressure and CO2	Juices	100 MPa
Pressure Cycling (HPC)	Extraction	300 MPa
Hyperbaric	Fresh Produce	900 kPa





Why High Hydrostatic Pressure or HPP?

1. Independent of product mass, size and geometry
2. Minimizing treatment time and scale up
3. Inactivates all vegetative bacteria and spores
4. Destroys enzymes
5. Minimal impact on quality and nutrition
6. Commercially economical processes



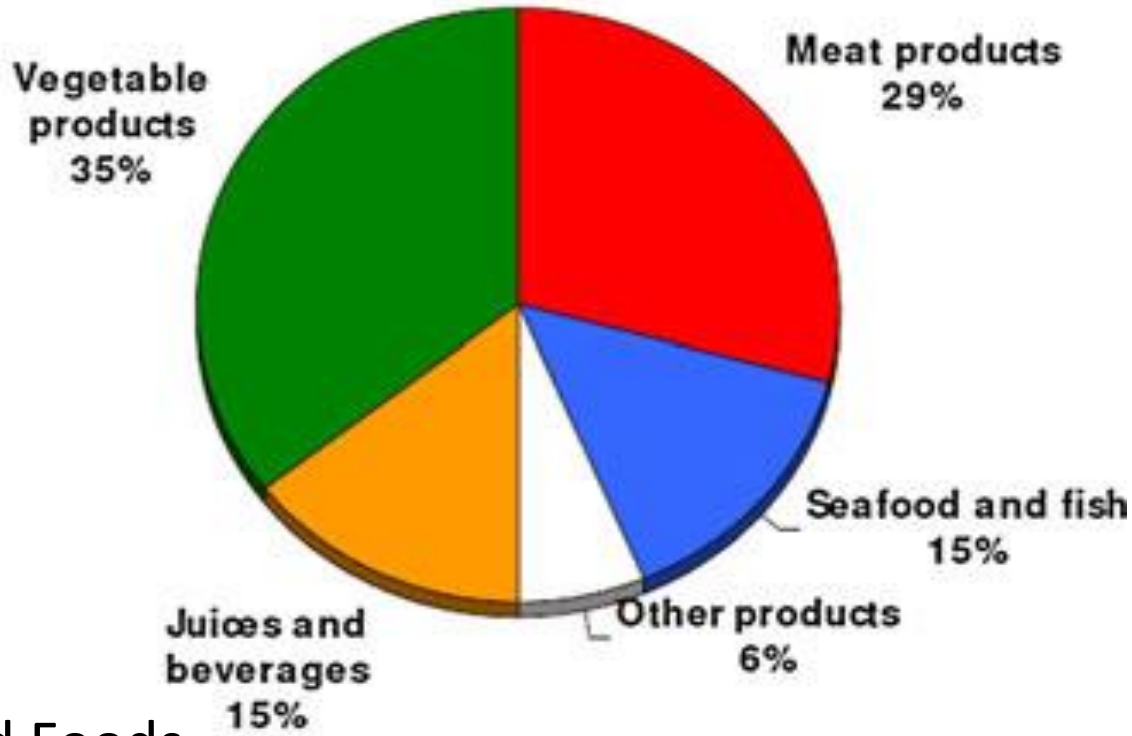
Markets of HPP Products

Emerged

- RTE meals and meats
- Raw seafood
- Juices

Emerging

- Harvesting treatment
- Pre-treatment
- Sterilization of Low Acid Foods
- Raw Pet Food



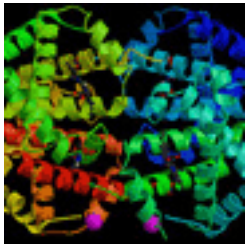
Companies Using HPP Technology

- **Food**

>100 companies

RTEs, juices, fruits, vegetables, seafood, avocados, hummus, dips, vines, cleanses, mussel powder

- **Biotech**

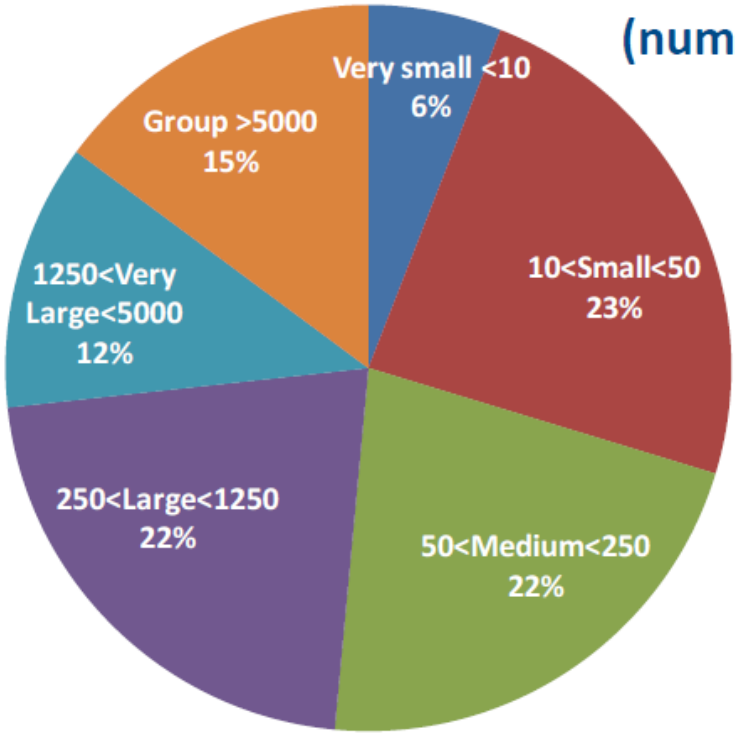


- BaroFold
  - disaggregation and controlled refolding of proteins
- Pressure BioSciences Inc
  - Instruments using pressure cycling technology

HPP Users Size Profile

Source: Hiperbaric

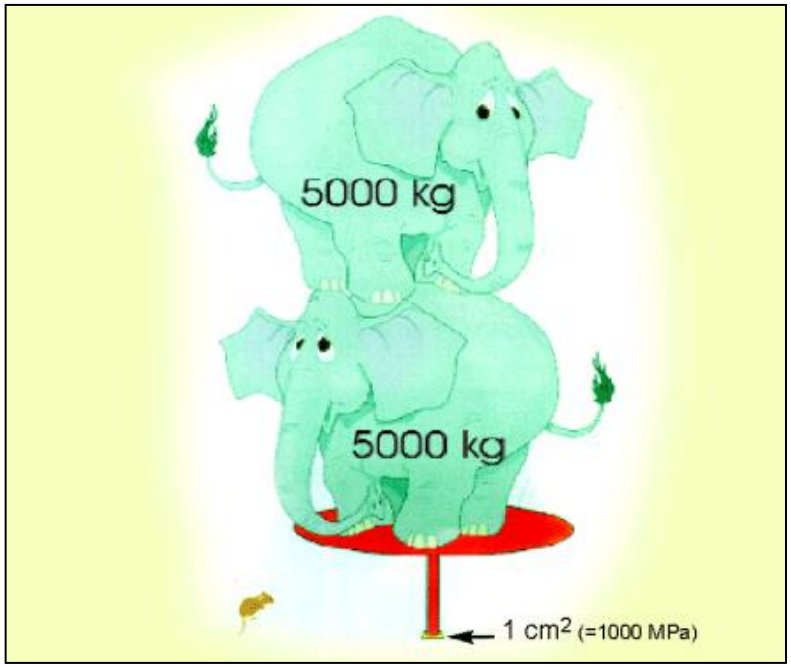
(number of employees)

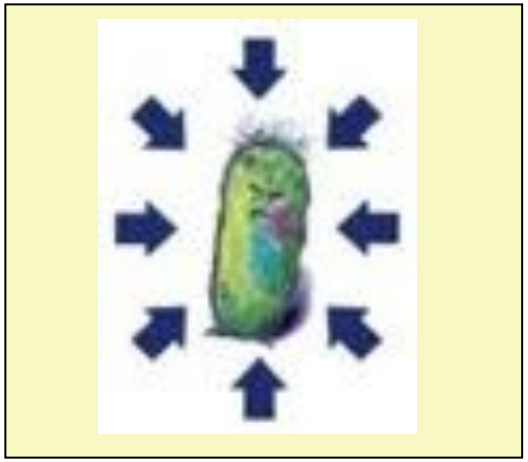


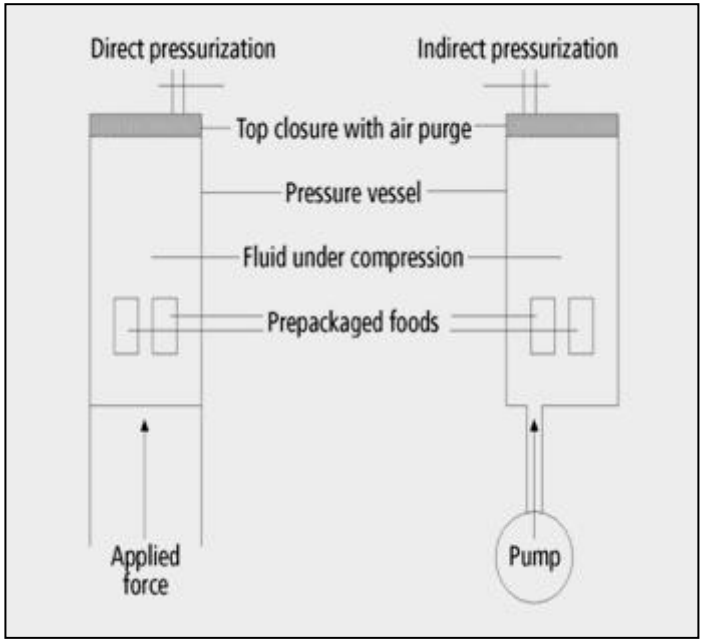
- 100 different HPP users companies in the world
- 51% are SME < 250 employees

I. FUNDAMENTAL PRINCIPLES

Principles of High Hydrostatic Pressure







In-Container Principle

- Product is generally treated in its final primary package
- Food and its packaging are treated together
- Entire package remains a “secure unit” until the consumer opens it
- Packaging must withstand a change of volume up to 18% followed by return to its original size
  - Without loosing package integrity
  - Seal integrity
  - Barrier properties
- Packaging under vacuum or modified atmosphere

Fundamentals of High Hydrostatic Pressure

1. ***Isostatic Principle***

   Transmission of pressure is uniform and instantaneous (independent of the size and geometry of the food)

2. **Le Chatelier's Principle**

   Any phenomenon in equilibrium (chemical reaction, phase transition, change in molecular configuration) accompanied by a decrease in volume can be enhanced by pressure and vice versa

3. ***Microscopic Ordering Principle***

   at constant temperature, an increase in pressure increases the degree of ordering of the molecules of a substance.

Hierarchy of Pressure Effects

Increasing Pressure

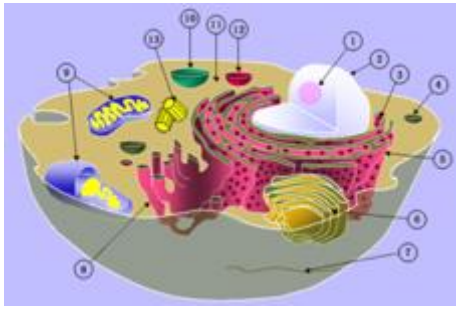
ΔP

Denaturation of Nucleic Acids (molecules)

Denaturation of Proteins (monomeric) (macromolecules)

Disassociation of Complex Structure (multimeric lipids polysaccharides)

Disruption of Viruses (cells)



Killing of Cells, Bacteria, Fungi (organisms)

HPP Effects on Pathogenic Bacteria

- **Normally: Spore > gram (+) > gram (-)**
- Heat-resistant bacteria are usually more pressure-resistant than heat-sensitive types
- Pressure resistance often reaches a maximum at ambient temperatures
  - initial temperature of the food prior to HPP can be reduced or elevated to improve inactivation at processing temperature
- *Listeria monocytogenes* and *Staphyloccocus aureus* are the most well-studied
- *Staphyloccocus aureus* appears to have a high resistance to pressure
- Clinical isolate of *E. coli* O157:H7 that possesses pressure resistance comparable to spores
- Variability of pressure resistances within strains of *S. aureus*, *L. monocytogenes*, *Salmonella* and *E. coli* O157:H7 was demonstrated
- Pressure resistances with species diminished significantly when the pressure treatment temperature was raised from 25 to 50 °C

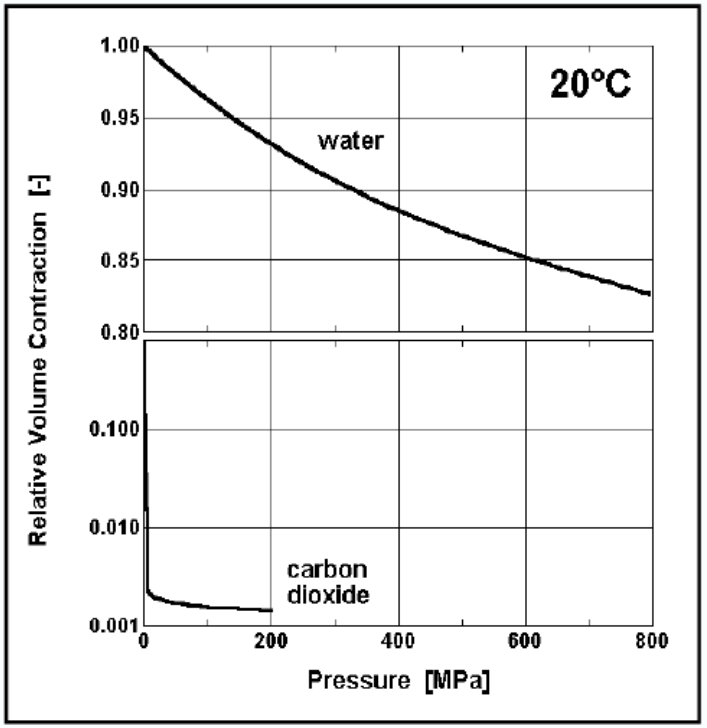
HPP Effect on Enzymes

- Vary depending upon targeted enzyme
- Some enzymes are inactivated
- Some enzymes demonstrate no effect
- The activities of some are enhanced by HHP
- Blanching?

Enzyme	**Inactivation**
Pectinmethylesterase	yes
Alpha-amylase	Yes
Lipoxygenase	Yes
Polygalacturonase	No
Peroxidase	No
Polyphenoloxidase	No
Papain	No

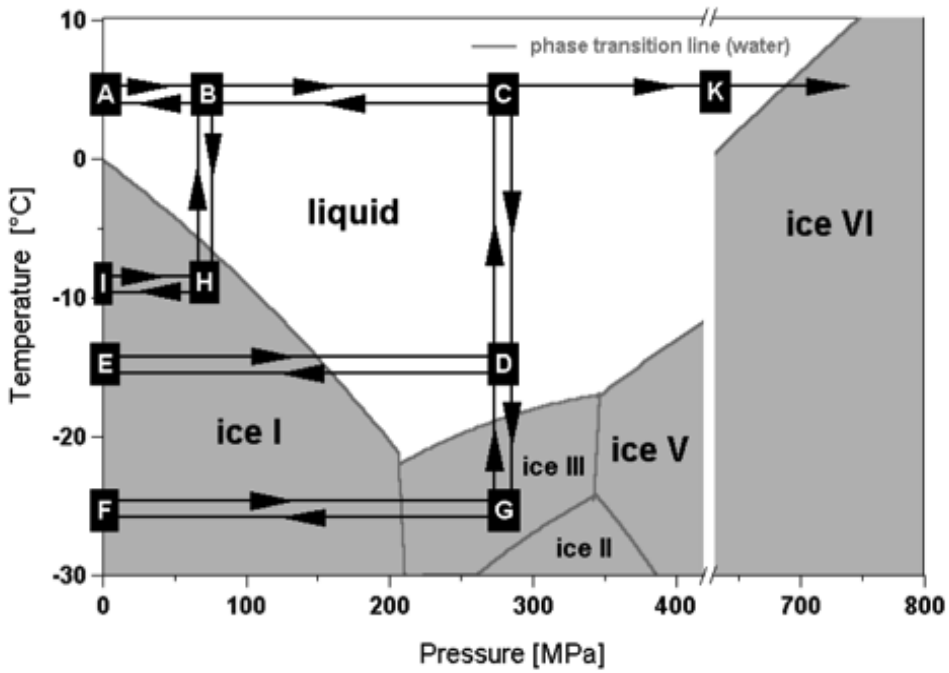
Changing Food Properties

- Water
- Solidify lipids
- Changing chemical reactions
  - Denaturate proteins
  - Inactivate/activate enzymes
  - Hydrolysis
  - Maillard reaction
  - Lipid oxidation
- Sensorial and nutritional properties
- Texture
  - dairy products, meats, gelatinization of starch



Compressibility of water and carbon dioxide at 20°C.

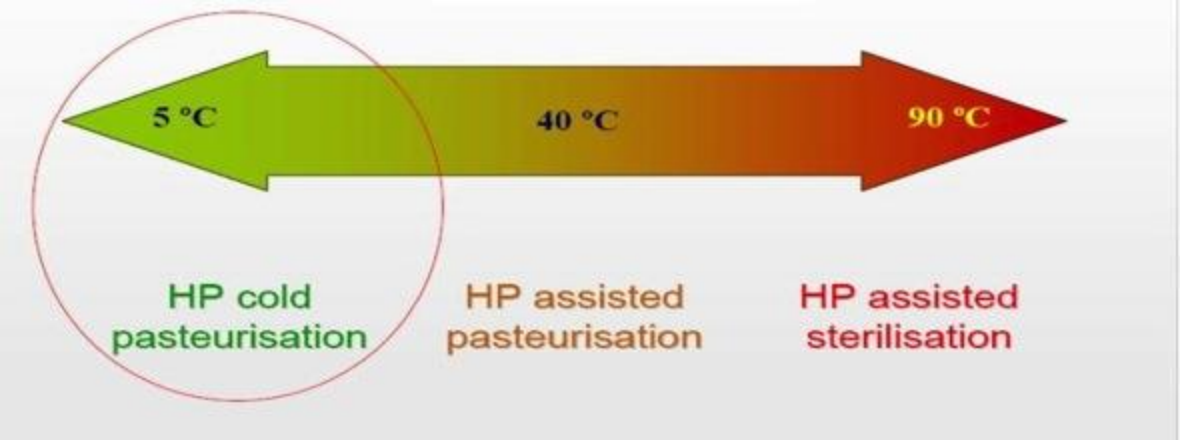
Freezing-Thawing Processes Under High Pressure



- HP depresses the freezing/melting point to a minimum of –22°C at 210 MPa
- Higher density ice exists under HP above 210 MPa known as ice I-V
- Pressure assisted freezing
  - (A-B-H-I)
- Pressure assisted thawing
  - (I-H-B-A)
- Pressure shift freezing and thawing
  - (A-B-C-D-E) & (E-D-C-B-A)

Thermal or Non-thermal?

- Can be used in combination with mild or high temperature



- Depends on process, system, product temperature prior to HHP
  - must be cooled or heated up

- Product composition such as air, water/oil/fat content must be taken into consideration
  - Water ~ 3°C/100 MPa
  - Lipids ~ 6-9°C/100 MPa

$$\Delta T = \sum_i (\Delta T x\, I_i)$$

Adiabatic Temperature Increase

Function of

- Thermo-physical properties
- Initial temperature
- Pressure

$$\left(\frac{\partial T}{\partial P}\right)_S = \frac{\alpha}{\rho\, C_P} T$$

Affected by

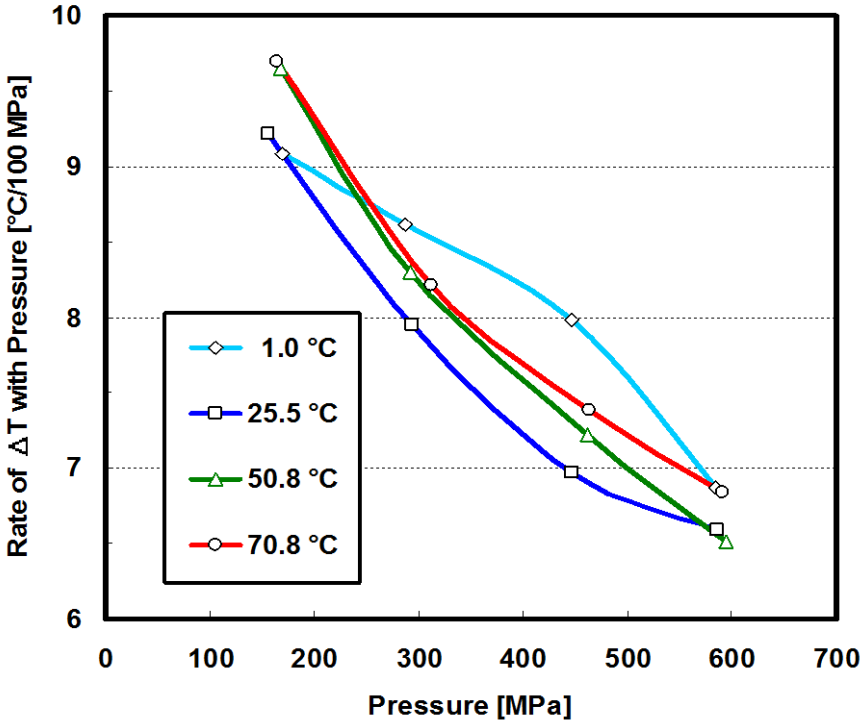
- Pressurization rate
- Food composition
- Boundary conditions (e.g. pressure medium)

Compression Raises Temperature of the product

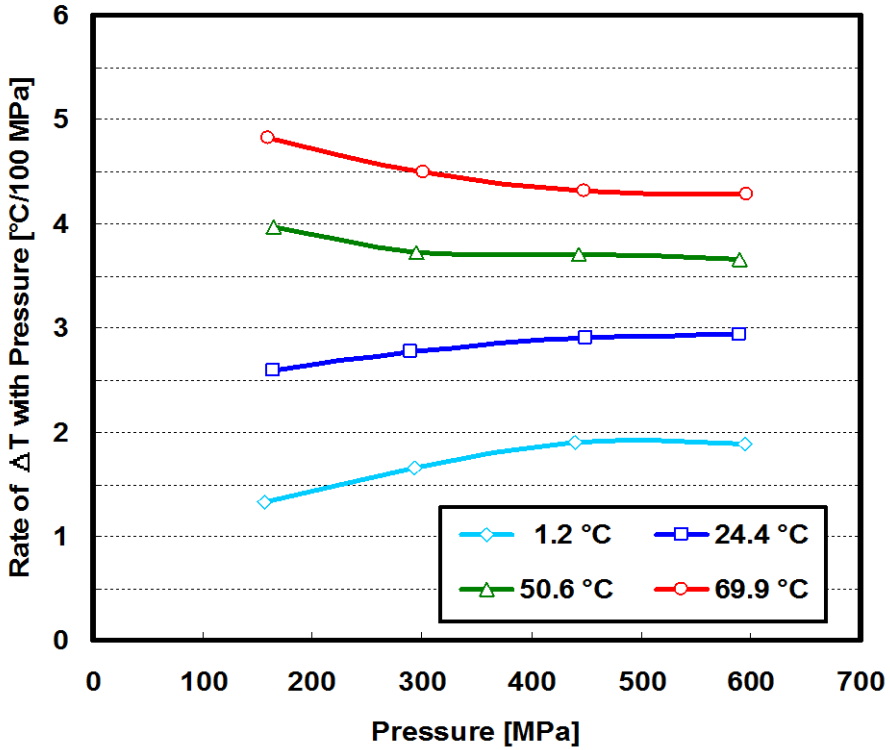
2- 8°C per 100 MPa

Adiabatic Heating of Oil Vs Water

[100$\Delta T/\Delta P$ (°C/100MPa)]



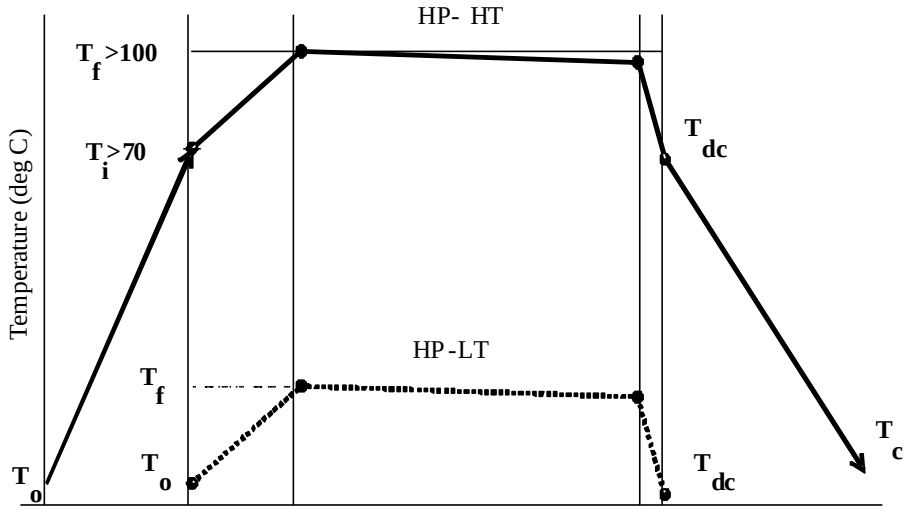
Vegetable Oil



Water

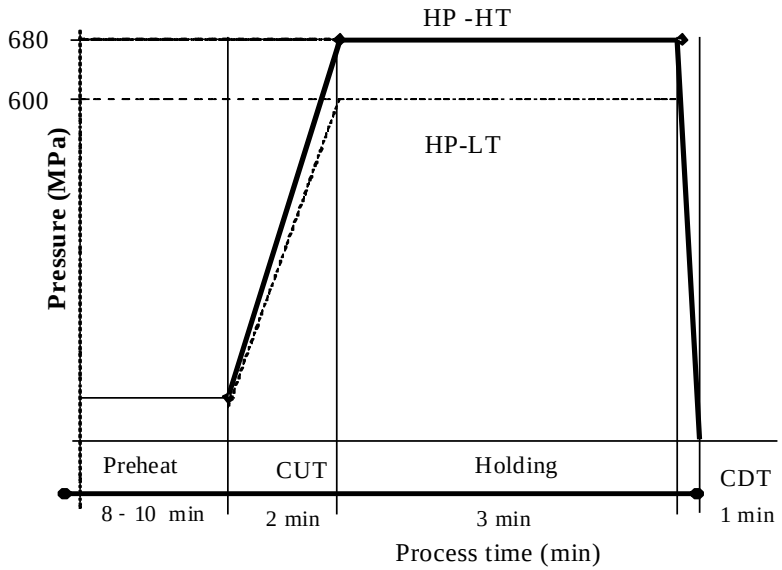
Patazca, Koutchma et al 2005, JFE

HPP Processing Cycle



HP-HT – sterilization

600 MPa < P < 900 MPa
100°C < T < 130 °C



HP-LT - pasteurization

300 MPa < P < 600 MPa
4 °C < T < 45°C

HPP Process Parameters

Process Pressure - constant holding pressure

- >700 MPa – “sterilization”
- 300-600 MPa – “pasteurization”
- <300 MPa – raw product treatment

Process Temperature –

final product temperature after pressurization

- >90 C – sterilization
- 20-50 C – pasteurization
- 4-20 C – raw products

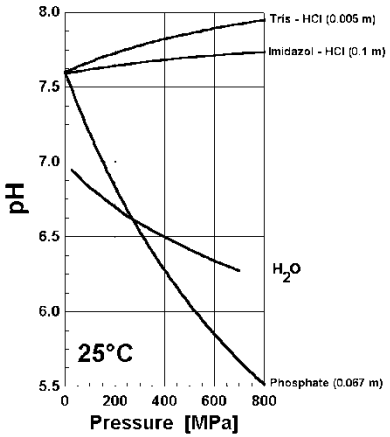
Process hold time

Time recorded between end of compression and start of decompression

Other Parameters Affecting HPP

Product

- pH, water activity
- Composition:
  - Fat
  - Salt content
  - Sugar

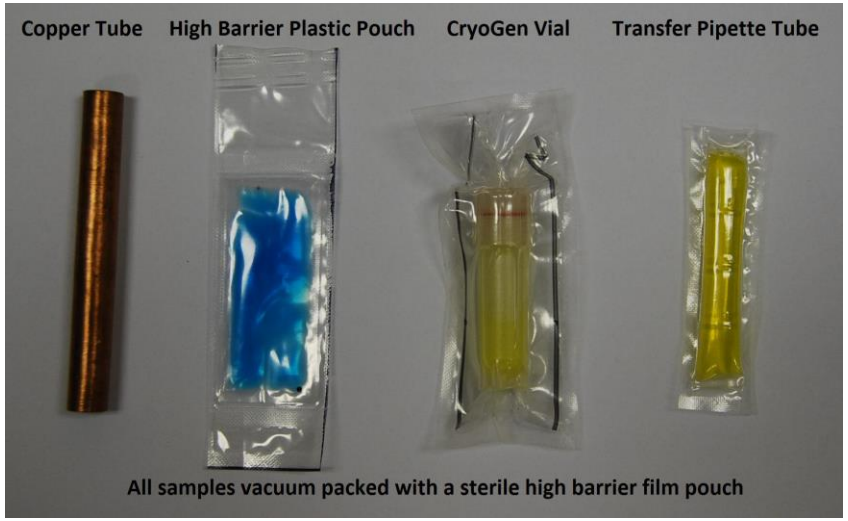


Physiological state of bacterial cells

- From exponential or stationary growth phase

Packaging

- Type of packaging:
  - vacuum or MAP
- Packaging and material influence the log reduction
- Design and geometry



Critical Product And Process Parameters For Establishment of HPP Process

	HHP pasteurization	**HHP sterilization**
Product parameters		
pH, a_w	3.5 <pH<4.6; pH<3.5	pH>4.6; a_w >0.86
Process parameters		
Temperature, ^oC	≤ 45	> 100
Pressure, MPa	≤ 600	> 700
Target microorganisms		
Pathogenic	*E. coli; Listeria; Salmonella*	*C. botulinum* spores
Spoilage	Lactic bacteria, yeasts, molds	*Geobacillus* spp. *Bacillus cereus*
Storage	Refrigerated conditions	Ambient temperature
Packaging	**Hermetically sealed flexible containers**	**Hermetically sealed flexible containers**

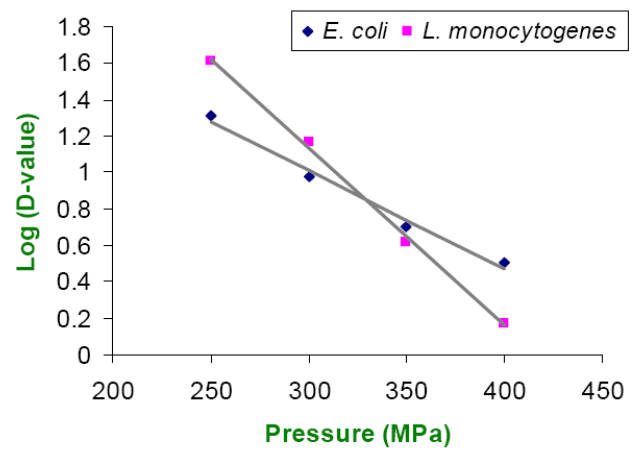
HPP Pasteurization Process

Requires Data

- HP inactivation of pathogenic bacteria
  - *Listeria, E.coli, Salmonella, Staphylococcus aureus, Campylobacter*
- Effects of pH, water activity and composition
- HP inactivation of spoilage m/o
  - Yeasts and Molds, Lactic bacteria
  - Aspergillus?
- HP destruction of enzymes
- HP effects on quality changes
- Process validation

$$D_{P,T} = \frac{t}{\log\left(\frac{N}{N_0}\right)}$$

Decimal Reduction Time Curves

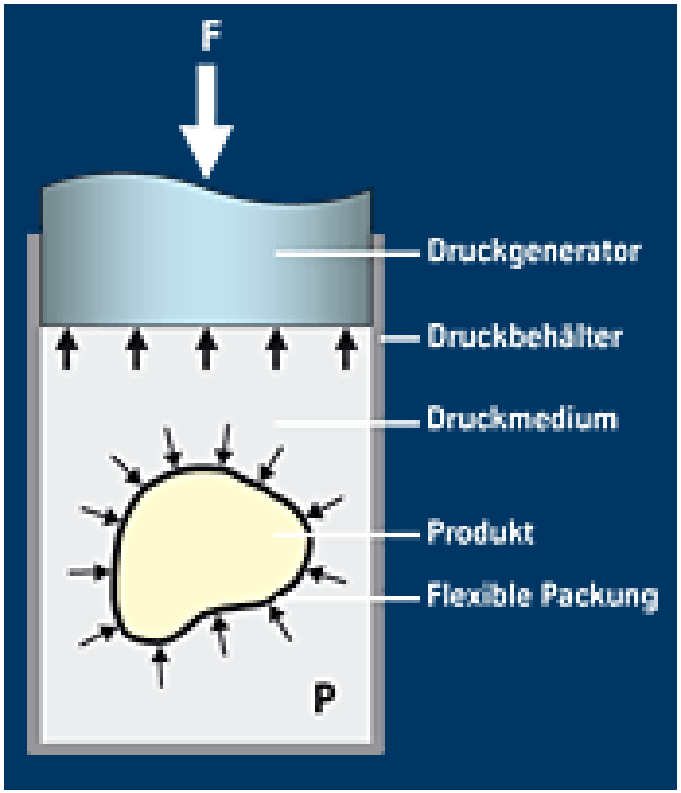


Zaman, 2005

$$z_P = -\frac{1}{[slope]} = \frac{(P_2 - P_1)}{\log\left(\frac{D_{T,P_1}}{D_{T,P_2}}\right)}$$

Product Development Issues

- Product selection
- Product formulation
- Food safety/regulatory
- Pre & post pressure processing
- **Packaging**
- Product storage temperature
- Shelf-life



Isostatict Pressure:
Homogeneous Treatment
of the Product

II. APPLICATIONS

High Hydrostatic Pressure

- **Preservation**
  - Sterilization
    - PATS
    - LAF
  - Pasteurization
    - RTE meals
  - Shelf-life extension
    - Fruit and Vegetable Products
- **Transformation**
  - Meat Protein
- **Value Added**
  - Seafood

HPP for Meats

Harvest
< 350 MPa

- Removal of hair, toenails
- Decontamination

Fresh
< 350 MPa

- Shelf life extension
- Improve quality

Ready-To- Eat
500 – 700 MPa

- Pasteurization
- Sterilization

Raw Meat Processing

Ambient Temperature at Pressure < 350 MPa

Harvest Processing → Fresh Meats

- Hair/feather removal
  - Loosens hair/feather follicles
  - Eliminates scald tank

- Toenail removal
  - Loosens toenails from hoof
- Reduces fecal contamination

- **Shelf-life Extension**
  - Stops post-mortem glycolysis
  - Improves meat quality

  - Stabilizes pH >6.0
  - Improves color
  - Increases water-holding capacity
  - Decreases shear force
  - Increases tenderness

HPP Potential in Low Sodium Products

Pre-treatment

- HPP may have beneficial effects on meat product quality
  - Improves water holding capacity and decreased water losses
  - Induce changes in protein
- Pressures: **50 up to 300 MPa**
- Temperature: Refrigerated or Ambient
- Time: up to 5 min

Post-lethality

- HPP is effective intervention methods against *Listeria* and other pathogenic bacteria
- Pressures: **500 up to 600 MPa**
- Temperature: ambient Refrigerated or Ambient
- Time: up to 3min

HPP Preservation of RTE products

Shelf Life Extension
Pasteurization

- Marinated Meats (13-15 days)
- RTE meats and poultry (ESL)
  - Pre-treatment
  - Post- Lethality (up to 66 days)

Ambient & Mild Temperatures
400 – 600 MPa

Sterilization

- Pre-packed
- Low Acid Foods (LAF) MREs
- Pressure Assisted Thermal Sterilization (PATS)

Elevated Temperature (>100°C)
700 MPA

Pasteurization for Meat and Poultry

- The NAMP petitioned USDA-FSIS to allow the term "Pasteurized" to be used for labeling qualified meat and poultry products

- Raw and cooked products
  - Packaging
  - Cooking
  - HHP
  - Irradiation

- Lead to the widespread adoption of pasteurization technologies

HPP for Seafood and Fish

Effects

Reduces

- Spoilage organisms
- Pathogens
- Viruses
- Parasites

Activates and Inactivates Enzymes

Does not changes taste

Separates muscles from shell

Applications

Potential to produce premium chilled vs frozen; Value-added products

- Extension of shelf-life and

pathogen control

  - Fish fillet
  - Oysters
  - Crab meat
  - Smoked fish
- Shucking oysters
- Separating shell in lobsters, crabs
- Pressure assisted thawing

HPP-treated Seafood on Market

Product	Process	Packaging	Effects
Oysters	240 MPa, 90 s 10-15 days shelf-life	No	Opening of the shells (kept closed by a plastic band). Destruction of Vibrio vulnificus. Marketing of fresh and frozen opened oysters
Ready-to-eat fishes: salmon, hake	2 months shelf-life	Skin vacuum packed	Listeria destruction. Increase in shelf lifeand additives reduction. Ready to eat 1.5 min in microwave oven
Desalted cod	600 MPa	Vacuum packed	Shelf life increase, sanitation

HPP for Fruit and Vegetables Juices

New Applications

- Super premium
- Cold pressed
- Smoothie like taste and texture with fiber
- High nutrients content
- 3X-10X shelf-life

Orange Juice Pasteurization

Thermal

90°C for 1 min

inactivates

Pectinmethylesterase (PME)

HPP

800 MPa 25°C 1 min

inactivates

Pectinmethylesterase (PME)

Raw Pet Food Category

Which Chubs are HPP &
Which Chubs are not?

HPP Drinkable Soup-Salad

Convenience soups

- *Frozen*
- *Retorted*
- *Aseptic*
- *Dehydrated*

- **HPP Gazpacho Alcaraz**
  - *Combines the thirst-quenching virtues of a cold drink with the nourishment of a salad*
  - *Made of local vegetables*
  - *Raw and fresh*

HPP Pasteurization

HPP @ 600 MPa - 3 min + 20°C

HPP @< 500 MPa -2-5 min + mild temperature

- Applications
  - Milk processing for cheese and yogurt
  - Dairy products
  - Juices, smoothies, jams
  - Egg products
  - Ready-to-eat meats
  - Ready-to-eat meals

Regulatory Status

USA

- USDA has approved High Hydrostatic Pressure as an intervention method for *Listeria* contaminated pre-packed ready-to-eat (RTE) meat products

Health Canada – Novel Foods Decisions

- Use of High Hydrostatic Pressure for Processing Ready to Eat (RTE) Meat-containing Entrees, Meat-containing Salads and Meat Products (Maple Leaf, December 2006)

- Use of High Hydrostatic Pressure for the Control of *L. monocytogenes* in Ready to Eat (RTE) Meats and Poultry (Santa-Maria, Foods, October 2006)

- Applesauce and apple sauce/fruit blends (2004)

PATS Process

- In February 2009, the US FDA approved a petition for the commercial use of Pressure Assisted Thermal Sterilization process (PATS) for application in the production of LAF
- Process filed for processing in a 35 L high pressure sterilization vessel
- To achieve a commercially sterile food product, PATS utilizes a combination of high pressure and temperature over a short hold time.
- The rapid temperature increase during compression and temperature decrease in the product upon decompression is a unique technology benefit.

III. COMMERCIAL HPP SYSTEMS

Commercial HPP systems

Vessel layout – horizontal

Automatic loading / unloading

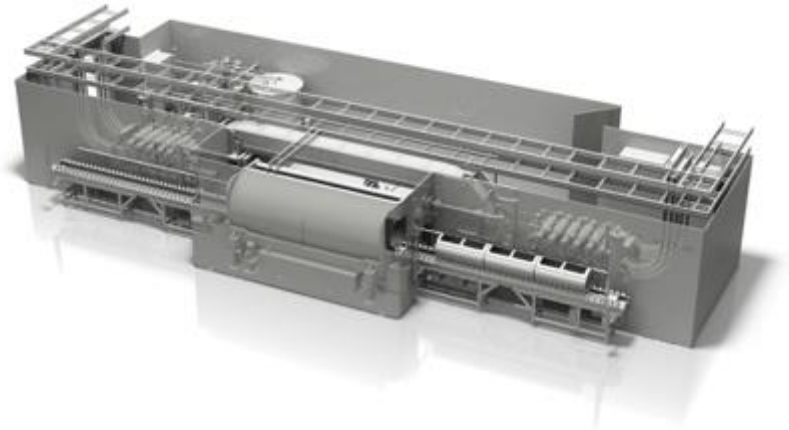
- Wave 6000 / 55 L
- Wave 6000 / 135L
- Wave 6000 / 300T L
- Wave 6000 / 420 L
- Wave 6000 /525 L

- Maximum pressure – 600 MPa
- Pressure Hold Time – 3 min

Commercial HPP systems: Avure

- Wide range of HPP systems
  - 100 L - 600
  - 215 L - 600
  - 350 L - 600
  - 687 L - 300
  - 525 L - 600

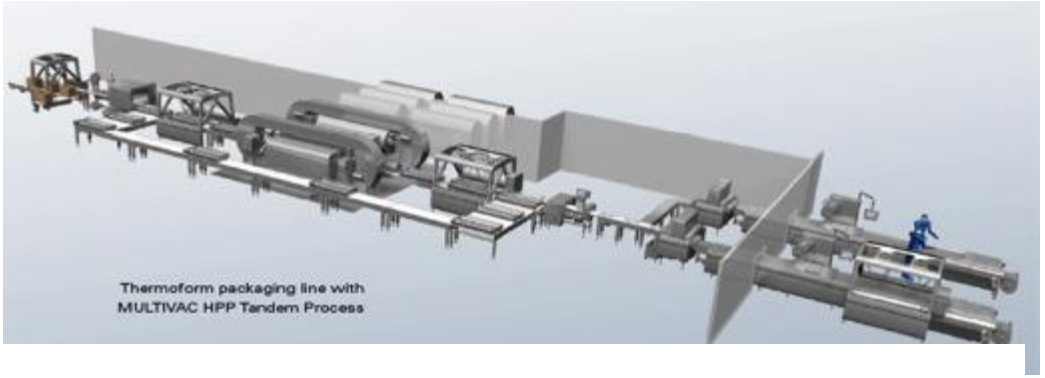
- >7 contract services facilities

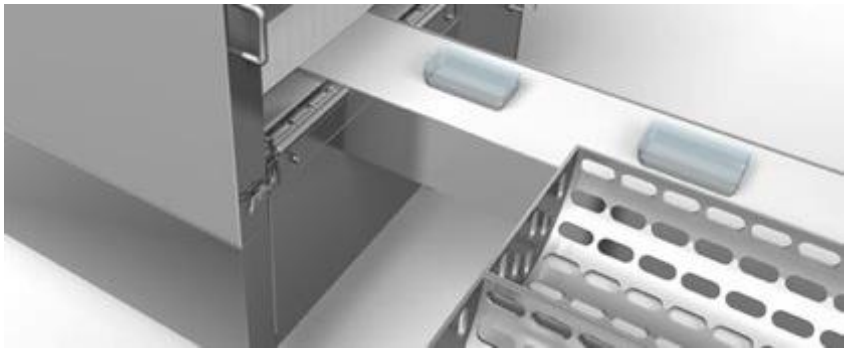


The 525L delivers 8,135 pounds (3,690 kg) of HPP processing per hour

Multivac and Uhde

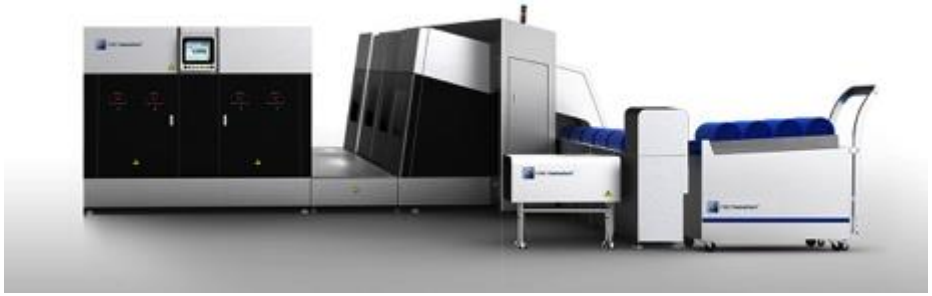
- Multivac for HHP packaging line
- Fully automated and integrated production lines
  - Filling, loading and unloading robots, inspection, weighting
- Continuous production flow

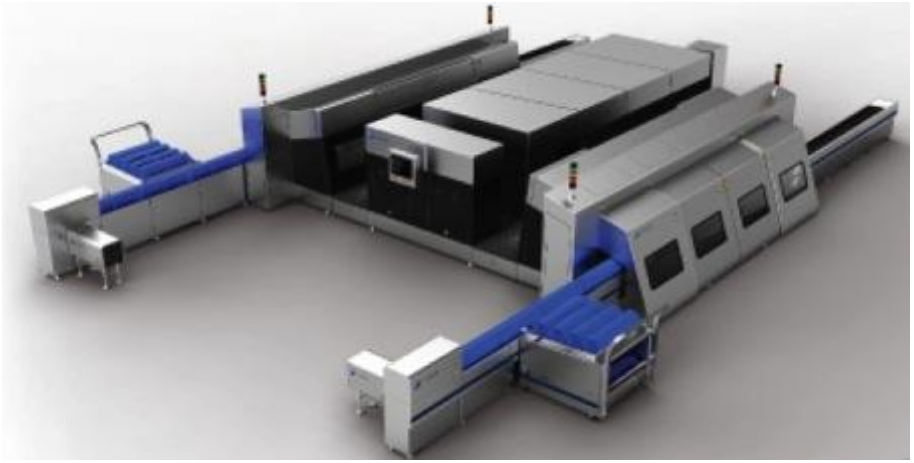




http://us.multivac.com/our-products/hpp-high-pressure-preservation.html

FresherTech





- Mono - Single Chamber Systems
- Duo - Dual Chamber Systems
- Quattro - Four Chamber Systems

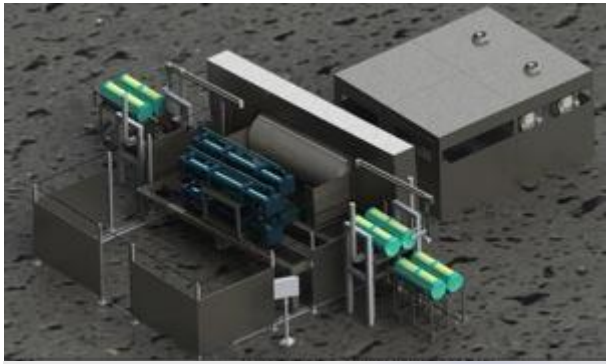
Fresher Evolution

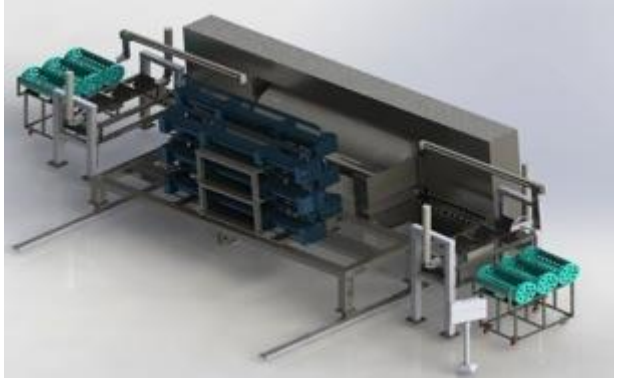
Newest manufacturer in North America

- 175L/600
- 350L/600
- 525L/600

- Longest lasting vessel in industry (Autofrettage) operating at 600MPa

- Lowest maintenance cost design

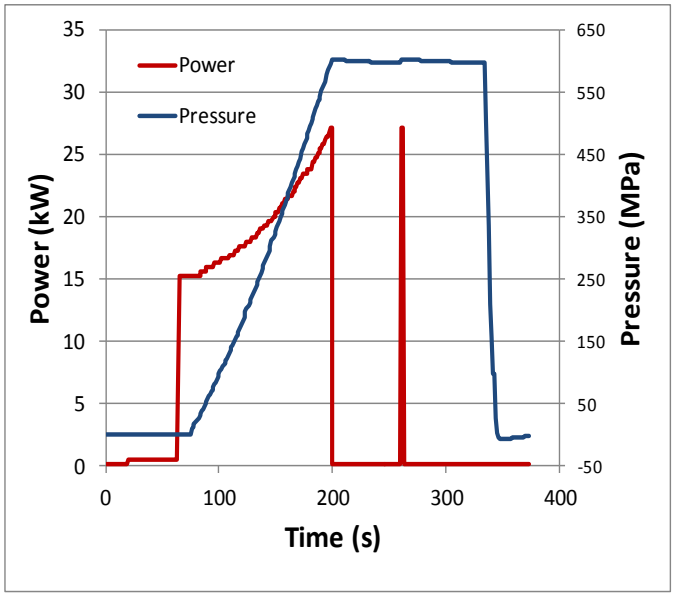


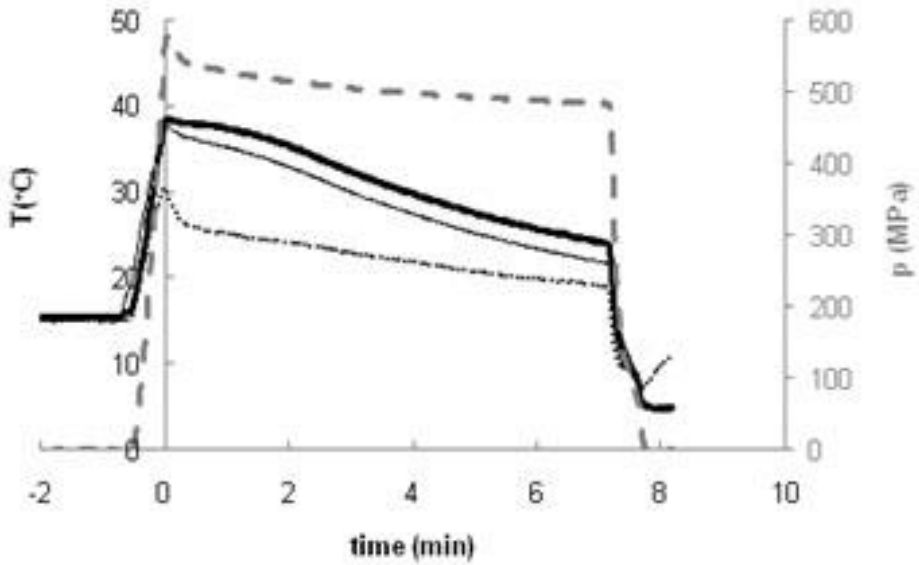


HPP Processing Cost

- Large initial investment and high operating costs
  - Produce as much as possible
    - Filling degree
    - Loading-Unloading times
    - Pressurisation time

- Maintenance: Parts reliability
  - High maintenance cost – specialist
  - Proprietary parts hard to source

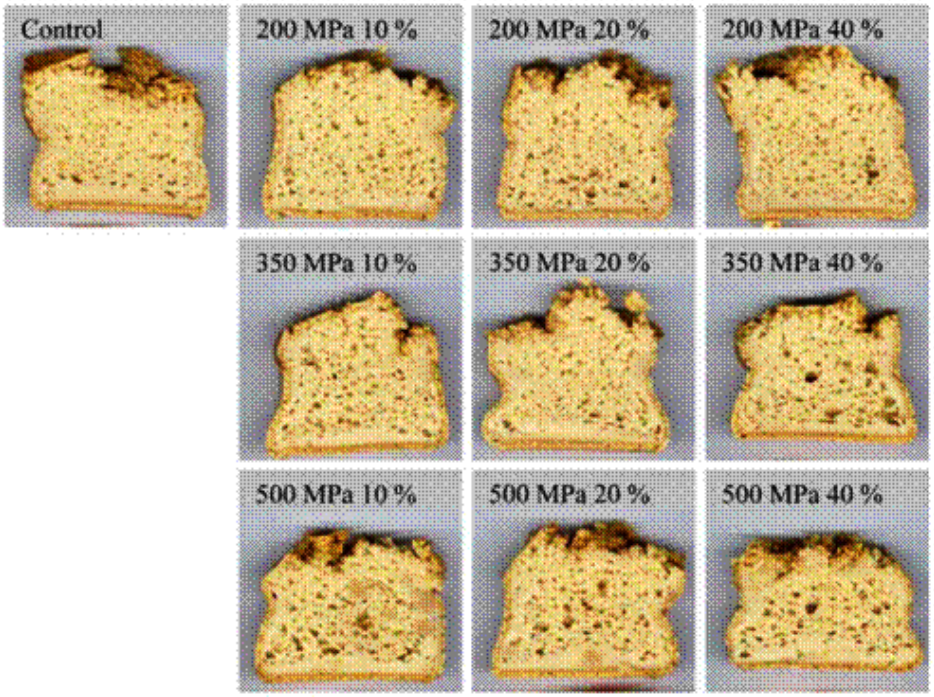




IV. CHALLENGES AND GAPS

Foods that Can't be HPP Treated

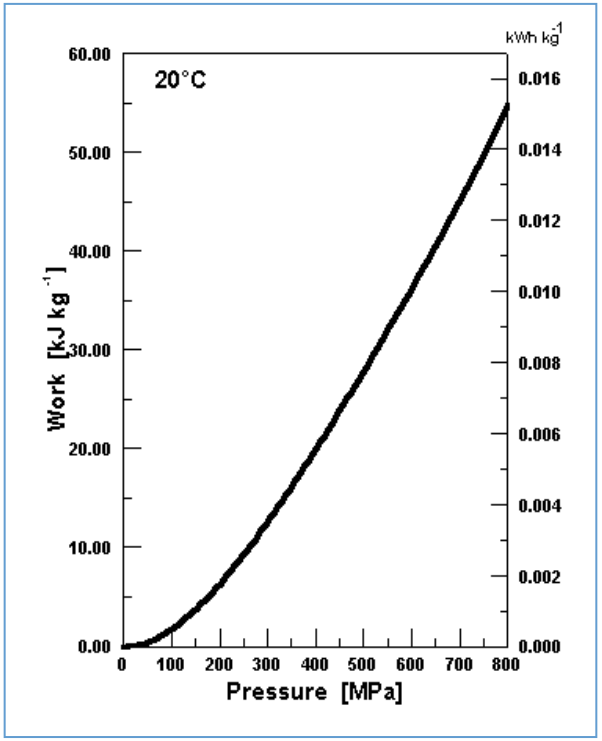
- **Solid foods with air included**
  - Bread
  - Mousse

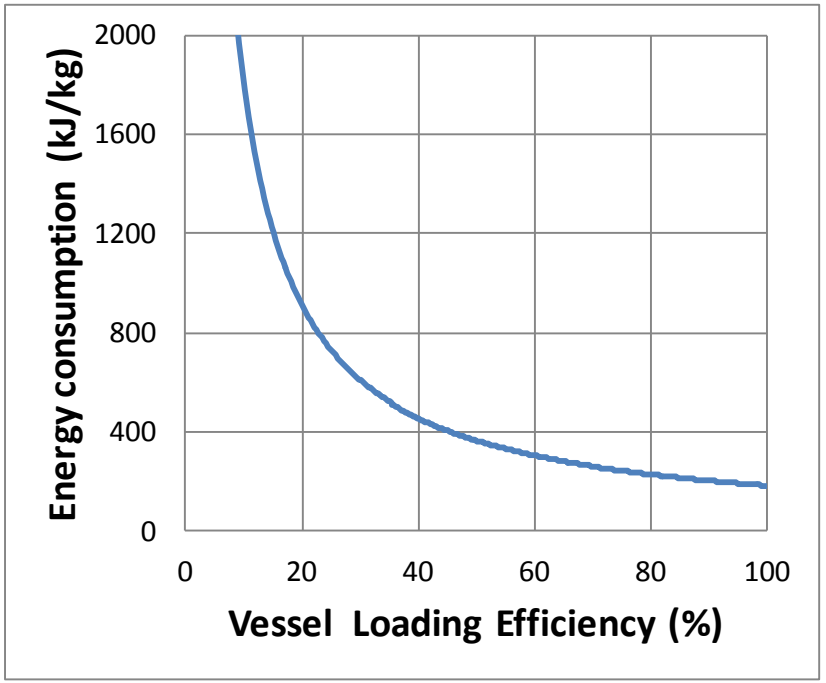


- **Packaged foods in completely rigid packaging**
  - In glass
  - Canned Foods

- **Foods with a very low water content**
  - Spices
  - Dry fruits

Energy Efficiency





$$E = P^2V / 2B$$

HPP: 55 kJ per kg of water at 700MPa

Steam Retort 210 KJ per kg to heat from 70- 120 ^{o}C

Knowledge Gaps

Incomplete inactivation
Tailing /Recovery
Spore inactivation

- MICROBIOLOGICAL

Mailard Reaction
Enzymes
Models vs Foods

- CHEMICAL

Starches
Proteinss

- STRUCTURE

HPP for Foods: Pros and Cons

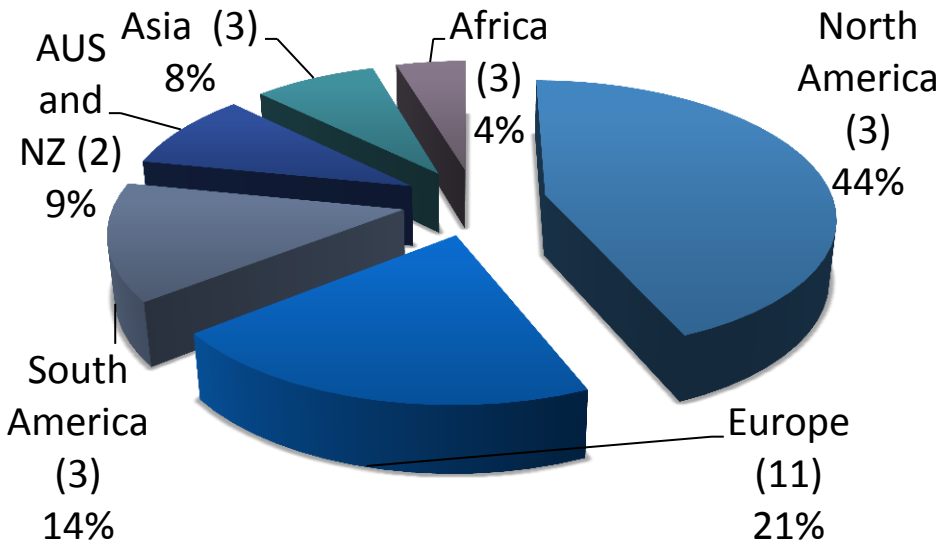
+++

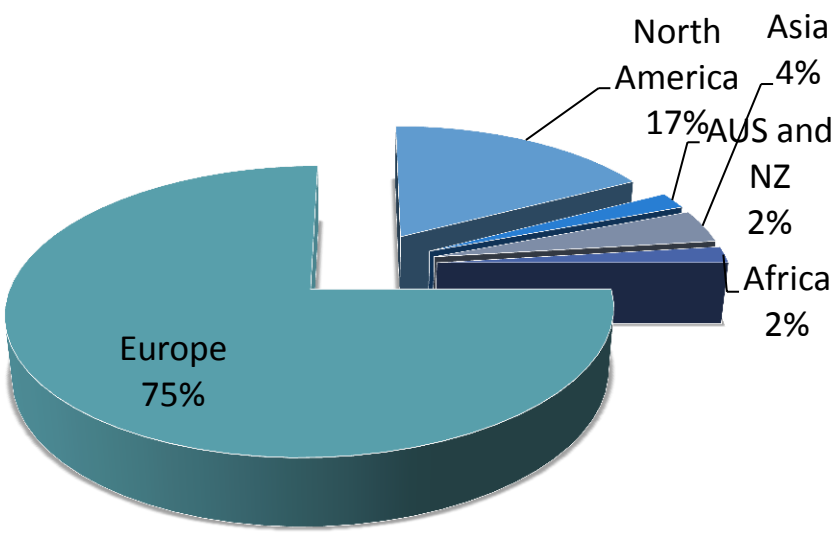
- New premium ESL products
- Clean Label Products
- Implement mild processing
- Shelf-stable products
- Accelerate enzymatic processes
- New products with unique textures by pressure-induced gelation and denaturation of proteins

--- ???

- Batch process
- Pre-packed products
- Cost
- Popular applications
  - Post-lethality treatment of RTE meals, seafood
- Limited application
  - Fresh meat and sea products
  - Fresh produce

Surveys Responders





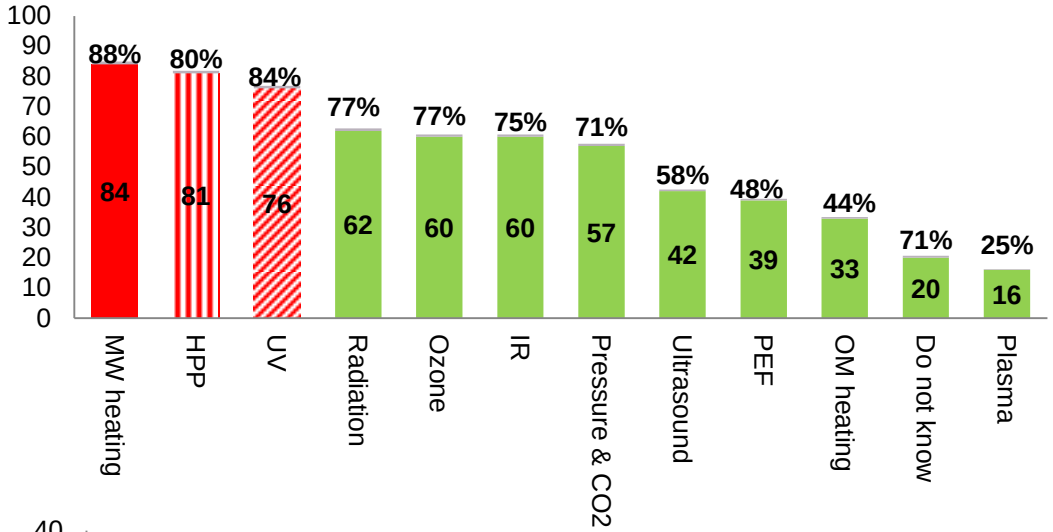
Survey 1: 25 countries

44% North America

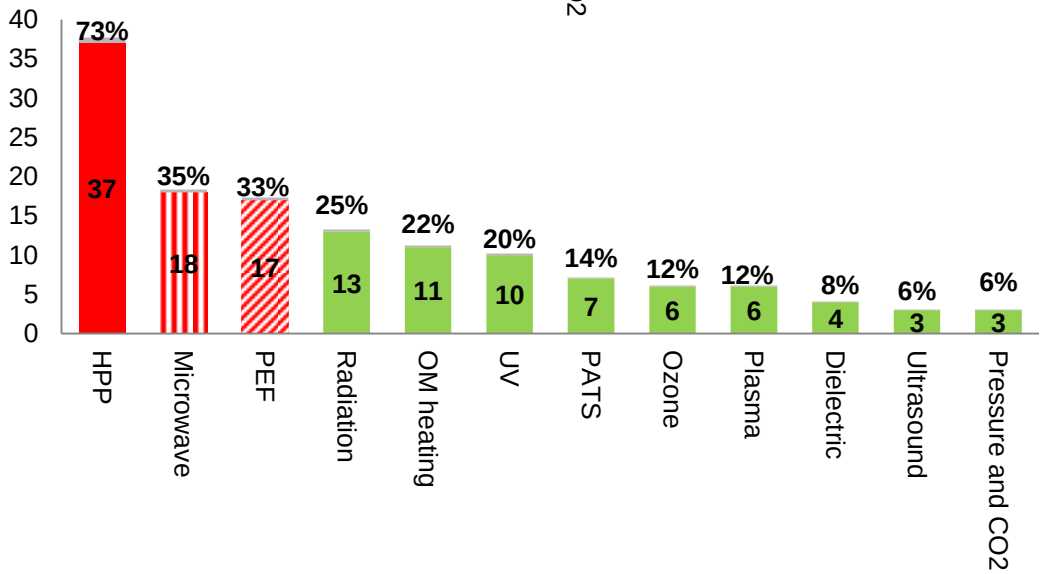
Survey 2: 16 countries

75 % Europe

Novel Food Processing Technologies



Survey 1: Commercial applications or Emerged in Food Production



Survey 2: Most significant technologies which are available now in their countries

Summary

- HPP is commercially available technology that solves consumers' demands for safety, healthiness, clean label and low sodium refrigerated foods
- HPP solves the retailers' needs for fresh foods with long shelf life
- Capital and operating costs of HPP systems are getting closer with the cost of chemical additives $.02 to $.08 per pound. HPP costs $.10 to $.35 per pound depending on fill and product shape.
- HPP allows processors to meet both retailer and consumer demands while potentially selling clean label products at a premium with the advantage of post package food pathogen inactivation

Questions?

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