NONTHERMAL PROCESSING OF FOODS AND EMERGING TECHNOLOGIES

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Summary

New trends in food processing, product development and quality assurance are promoting intense research on alternative methods for food preservation. Most foods are thermally preserved by subjecting the products to boiling (or even higher) temperatures for a few seconds to several minutes. These high-energy treatments usually diminish cooking flavors, and cause loss of vitamins, essential nutrients, and food flavors in the product. To overcome or minimize such disadvantages, the concept of nonthermal treatments was born. Nonthermal methods allow processing of foods below the temperatures used during thermal pasteurization, thus flavors, essential nutrients and vitamins undergo minimal or no changes during processing. Foods can be nonthermally processed by 1) irradiation, 2) high hydrostatic pressure (HHP), 3) the use of antimicrobials, bacteriocins, or chemicals, 4) ultrasound, 5) micro and ultrafiltration, and 6) electrical methods such as pulsed electric fields (PEF), light pulses (LP), and oscillating magnetic fields (OMF). Each of these techniques can be used either alone or in combination to optimize product quality, processing time, and bacterial and enzyme inactivation. Another advantage of nonthermal processes is that in general they utilize less energy than thermal processes.

Each nonthermal technology has specific applications in terms of the type of food processed. For example, high hydrostatic pressure, oscillating magnetic fields, antimicrobials, light pulses, and hurdle technology are useful in processing both liquid and solid foods, whereas pulsed electric fields are more suitable for liquid foods and irradiation is useful for solid foods. Furthermore, light pulses, irradiation and magnetic fields can be used to process prepackaged foods, reducing the risk of cross- or post-process contamination. Therefore, nonthermal technologies are not applicable in processing every variety of food. Each nonthermal technology has its merits and limitations, but in many cases, the use of a combined method or hurdle approach is necessary.

1. High Hydrostatic Pressure

1.1. Introduction

High hydrostatic pressure (HHP), also known as ultra high pressure (UHP), is not a novel technology to the food industry; however, modern consumer trends toward minimally processed foods in the 1990s have renewed interest in this technology. The first commercial pressure-treated food products were jellies and jams, appearing in the Japanese market during the early 1990s. More recently, some juices and purees were produced in Europe and America.

Exposing foods to pressures ranging from 300 MPa to 800 MPa for a short period of time, typically from a few seconds to several minutes, can inactivate the vegetative pathogenic and spoilage micro-organisms without the undesirable effects of heat. Other benefits of this technology include enzyme inactivation and gelation of proteins. Food freezing and thawing processes can be performed simultaneously with pressurization, yielding superior quality products. HHP also can retain nutritional and sensory attributes in food systems (see *Sensory Evaluation*), enabling the development of products with novel characteristics.

1.2. Engineering Principles

HHP technology is based on the use of pressure to compress food located inside a pressure vessel. Contrary to heat processes such as sterilization or pasteurization, HHP is a nonthermal process, as it only involves minor increases in temperature during pressurization. For a working pressure of 600 MPa, the temperature increment for pure water is only approximately 15ºC.

The applied pressure is isostatically transmitted by a fluid (Pascal's law). In this way, a uniform pressure from every direction compresses the food, which then returns to its original shape when the pressure is released. Pressure transmission is instantaneous, and independent of the product size and geometry. Contrary to heat, pressure transmission is not time/mass dependent, thus the time required for pressure to reach the internal points of the food processed is minimized. However, pressure effects on microbial inactivation and other food processing applications are time dependent.

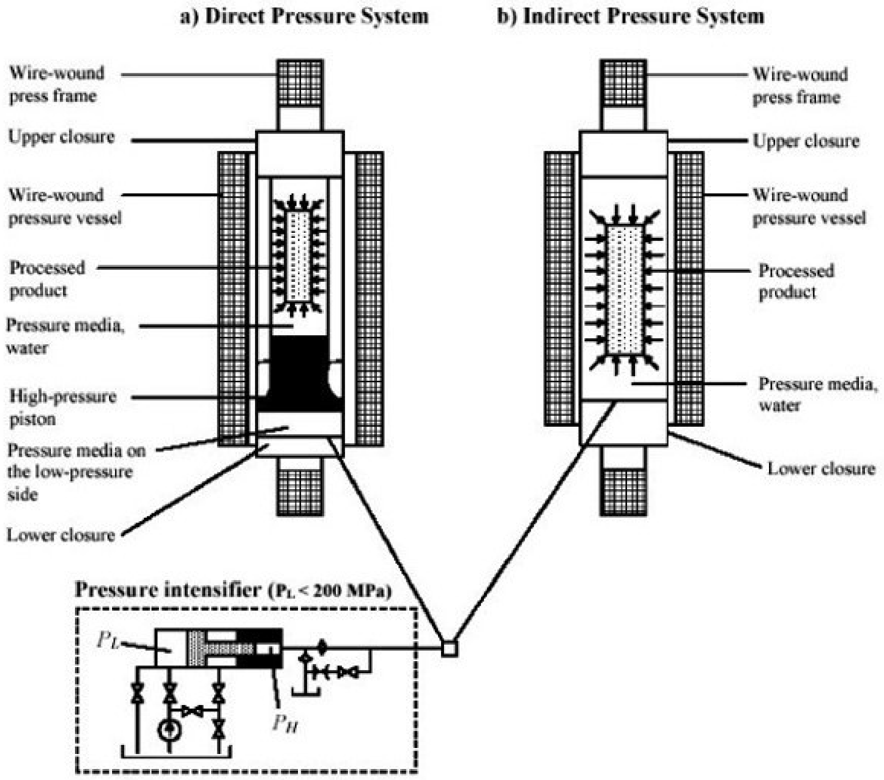

Figure 1. High-pressure machines with wire-wound vessels and two-pressure transmission systems.

The main part of a high-pressure machine is the cylindrical pressure vessel, frequently built in alloy steel of high tensile strength. The wall thickness is designed to endure the maximum working pressure and the number of cycles for which the vessel is intended. Multilayer or wire-wound pre-stressed vessels are used for pressures higher than 600 MPa (Figure 1). These vessels are deliberately designed with a residual compressive stress to lower the maximum stress level on the vessel wall during pressurization. In this way the wall thickness can be reduced, hence the cost of producing such an important part of the system can be lowered.

The pressure is essentially transmitted by two methods (Figure 1). In the direct method, a piston is driven at its larger diameter end by a low-pressure pump, which directly pressurizes the pressure medium. According to a hydraulic principle, the low pressure (P_L) exerted at the large surface end of the piston (A_L) is multiplied by the ratio of its surfaces to yield high pressures (P_H) at the small area end (A_H) of the piston.

$$P_L \times A_L = P_H \times A_H \Rightarrow P_H = \frac{A_L}{A_H} P_L \qquad (1)$$

The direct method of pressurization allows very fast compression but requires a pressure-resistant dynamic seal between the piston and the internal vessel surface.

In the indirect method, high-pressure intensifiers are used to pump the pressure media from the reservoir into the closed vessel until the desired pressure is achieved. Water is the most widespread pressure-transmitting media used in high-pressure food applications. One convenience of liquid water is that volume changes due to pressure are significantly lower than in vapor or other gases (e.g., for 600 MPa at 22ºC, the water volume decreases 15 percent).

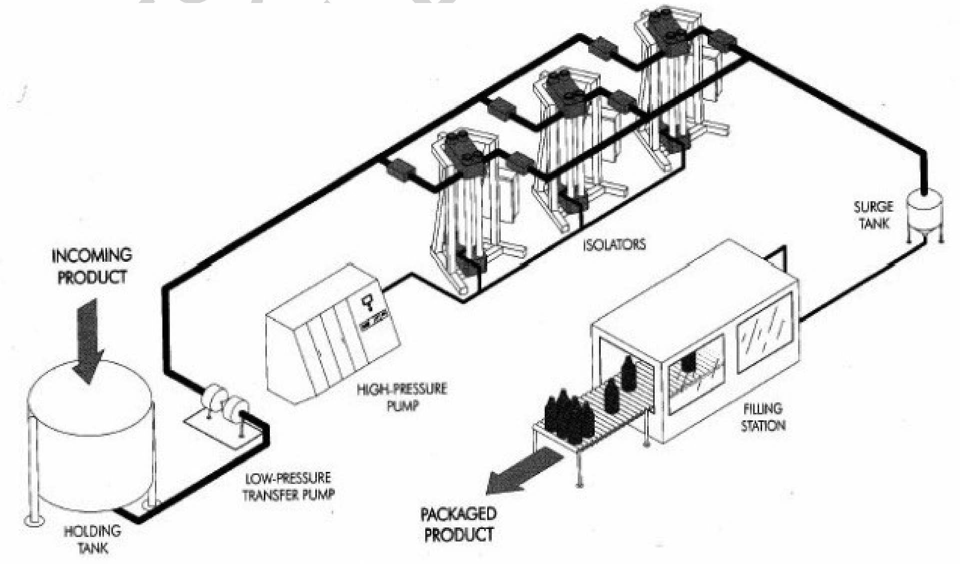

Figure 2. Semi-continuous high-pressure system.
(courtesy Flow Pressure Systems)

HHP is essentially a batch-wise process for pre-packaged foods, whereas semi-continuous process equipment is available for liquid foods (Figure 2). In both cases, the pressure treatment is carried out in cycles of three differentiable steps. An initial time is required to reach the desired working pressure (come up time), then a treatment time where the pressure is maintained, and finally the release pressure time, which is generally accomplished in a few seconds.

Food can be HHP-processed in two fundamental ways:

a) In-container, where high-pressure is exerted after filling and sealing the food into its final or intermediate package.
b) In-bulk, where no intermediate packaging exists, but aseptic or ultra-clean filling and sealing, which separates the pieces of equipment intended for contact with food from the pressure transmission media.

In the in-container mode, the main concern is the process efficiency obtainable, which is strongly related to the amount of product that can be processed per batch. In the in-bulk mode, the challenge is the aseptic design of the high-pressure vessel.

1.3. Biological Effects

High hydrostatic pressure causes microbial and enzyme inactivation, and protein denaturation, however, the basic mechanisms involved are only partially understood.
According to the Le Chatelier principle, under equilibrium conditions, a process associated with a decrease in volume is favored by pressure and vice versa.

Pressures between 300 and 800 MPa can inactivate food spoilage and pathogenic micro-organisms. Pressure induces a number of changes in the microbial cell membrane, cell morphology, and biochemical reactions, which can ultimately lead to microbial inactivation. Cell membranes are the primary site of action for pressure damage to microbial cells. The microbial membranes play an important role in the transport and respiration functions; thus, a great change in membrane permeability can cause death of the cell. Changes in cell morphology involve the collapse of intercellular gas vacuoles, anomalous cell elongation, and cessation of movement in the case of motile micro-organisms. There is good evidence that minor changes in the biochemistry of living cells play an important role in microbial inactivation. Biochemical reactions that are strongly influenced by pressure usually involve reactants and products differing in the number of ionizable groups, like water and acid molecules.

The extent of microbial inactivation achieved depends on the type and number of micro-organisms, the magnitude and duration of HHP treatment, temperature, and composition of the suspension media or food. In general, yeast and molds are more easily inactivated by pressure than bacteria. Among bacteria, vegetative forms are more susceptible than spores. The relative pressure sensitivity of vegetative cells makes them the first targets for preservation of foods by high-pressure technology, and particularly for products in which food properties (e.g., low pH in fruit juices) ensure that pressure-resistant spore-formers are unable to grow. Spore germination can be induced by altering moderate pressure cycles, which leaves the vegetative cells susceptible to inactivation. Grampositive bacteria are more resistant than gram-negative bacteria, and bacteria at the stationary growing phase are more resistant than bacteria at the logarithmic growing phase.

Generally, an increase in pressure increases microbial inactivation. However, increasing the treatment time does not necessarily increase microbial death rates. When combined with other preservation factors, such as water activity, pH, temperature or antimicrobials, pressure action can have an antagonistic, additive, or synergistic effect (see *Hurdle Technology*). Foods with low water activity achieved by high sugar concentrations decrease the sensibility of micro-organisms to pressure (antagonistic effect). Low pH and the use of combined moderate temperatures promote pressure efficacy (synergistic effect) on microbial inactivation.

Enzymes can be inactivated through pressure action by disrupting their active site. Enzymes are proteins in which biological activity arises from an active site brought together by the three-dimensional configuration of the molecule. Even small changes in the active site can lead to a loss of enzyme activity. Pressures above 150 MPa induce partial unfolding and dissociation of protein structures, due to modifications of hydrophobic and electrostatic bonds. However, HHP does not affect covalent bonds; thus, enzymes can refold after depressurization, partially or totally recovering their original biological activity. Since protein denaturation is associated with conformational changes, pressure action can change the functionality of the enzyme (e.g., increase or loss of biological activity or change in substrate specificity). Pressure alone is in general not enough to inactivate food deteriorative enzymes. Remaining enzymatic activity of deteriorative enzymes, if high enough, could severely reduce the shelf life of HHP-treated foods. However, when pressure is used in combination with other factors, such as mild heat treatment, enzyme inactivation can be attained.

The structure of food proteins and polysaccharides can be changed with high pressure to bring about modifications in rheology and mouthfeel (See *Food Rheology and Texture*). Pressure can induce the gelation of suspensions, solutions of various food proteins, such as muscle homogenates, surimi, egg white, and soy proteins. Gels obtained by HHP processing have lighter color and lower strength than gels obtained with traditional heat processing. However, the nutritional value of HHP obtained gels is better retained and their novel texture could potentially be used in food product development areas. Starch can be induced to gelatinize by pressure action. In heat-induced gelatinization, the granule molecular order is disrupted and amylose leaches while the granule swells. HHP disrupts the starch granule structure without leaching amylose, causing a limited granule expansion when swelling. Gels obtained from HHP gelatinized starches have a weaker matrix than heat-induced types.

Frozen food can be thawed with pressure treatment, decreasing the time required at atmospheric pressure, thus reducing the loss of liquid retention properties and improving the preservation of color and flavor in fruit. Thawing generally occurs more slowly than freezing, potentially allowing further damage to the sample. Therefore, pressure-assisted freezing and thawing represent a potential area of development, although few preliminary studies have been published thus far.

1.4. Future Trends

HHP technology offers the food industry a unique opportunity to develop new foods with superior nutritional and sensory quality, novel texture, more convenience, and increased shelf life. Although it is unlikely that pressure processing will replace food canning or freezing, due to high processing costs, HHP could find applications with high-quality products where thermal processes are not suitable or HHP could confer added value in terms of nutritional or sensorial characteristics.

2. Ultrasound

2.1. Introduction

The application of ultrasound in the food industry has been extensively researched and developed in different important areas, such as determination of food properties, plant sanitation, and food processing. The technology is based on the transmission of sound through liquid media at a frequency beyond the human audible range (e.g., above 18 MHz).

Ultrasound applications are typically divided into two categories according to the power and frequency utilized. Low power-high frequency ultrasound operates at frequencies in the MHz range and with acoustic power ranging from a few mW to several tens of mW. Such acoustic waves are capable of traveling through a media without altering the material, allowing non-destructive measurements of food processes. High power-low frequency ultrasound is operated at frequencies in the kHz range in which the acoustic power can extend from a few mW to kW. Examples of use for high power-low frequency ultrasound include surface sanitation, microbial inactivation, and enzyme activity alteration.

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Biographical Sketches

Gustavo V. Barbosa-Cánovas received his B.S. in Mechanical Engineering at the University of Uruguay and his M.S. and Ph.D. in Food Engineering at the University of Massachusetts-Amherst. He then worked as an Assistant Professor at the University of Puerto Rico from 1985-1990, during which he was granted two National Science Foundation (NSF) awards for research productivity. Following this, he went to Washington State University (WSU) where he is now Professor of Food Engineering and Director of the Center for Nonthermal Processing of Food (CNPF). Dr. Barbosa-Cánovas chaired the Organizing Committee for the 1997 and 1999 Conference of Food Engineering (CoFE). In addition, he is an Editor of the journal *Food Science and Technology International* published by SAGE, the journal *Innovative Food Science and Emerging Technologies* published by Elsevier Science, and the *Food Engineering* theme in the Encyclopedia of Life Support Systems (EOLSS) to be published by UNESCO. Dr. Barbosa-Cánovas is the Editor-in-Chief of the Food Engineering Book Series published by Kluwert Academic and Plenum Publishers (KAPP) as well as of the Food Preservation Technology Book Series published by CRC Press. He has chaired and organized several technical sessions at the American Institute of Chemical Engineers (AIChE) and Institute of Food Technologists (IFT) annual meetings, edited 12 books on Food Engineering topics, and has authored, among others, *Dehydration of Foods* (Chapman and Hall), *Nonthermal Preservation of Foods* (Marcel Dekker), *Food Engineering Laboratory Manual* (Technomic), and *Engineering Properties of Biological Materials* (ASAE). Dr. Barbosa-Cánovas is also part of the editorial board for four technical journals, including the *Journal of Food Engineering*, *Journal of Food Process Engineering*, *Journal of Food Science and Technology (LWT)*, and the *International Journal of Physical Properties of Foods*. He is International Consultant for the United Nations' Food Agriculture Organization (FAO), Associate Researcher for the United Nations' PEDECIBA (a special program to develop basic sciences), and a consultant for several major food companies in the United States.

M. Marcela Góngora-Nieto is a Research Associate with the Center for Nonthermal Processing of Foods at Washington State University, Pullman, WA, USA. She is currently working on a project for the scale up of nonthermal technologies in food processing, primarily in the area of Pulsed Electric Fields (PEF). M. Marcela Góngora-Nieto received a Ph.D. in Engineering Science from Washington State University in 2000. As a Ph.D. student, she worked on the new technologies involved in nonthermal preservation of foods. She co-authored the first specialized book in PEF technology, *Preservation of Foods with Pulsed Electric Fields*, published by Academic Press. (1999). Dr. Góngora-Nieto has co-authored 11 book chapters, 16 articles in refereed journals, and 27 presentations for international meetings. She actively participated as a Graduate Student Representative of the IFT Nonthermal Division, and continues to participate as a member today. She maintains active participation in the research of nonthermal technologies and their implementation, specifically in energy measurements and control systems. Also, Dr. Góngora-Nieto’s participation includes a strong interest in the regulatory aspects of nonthermal technologies, as well as in the promotion of interactions between, academia, industry, and government.