DOI: 10.2478/V10133-010-0057-8

HIGH PRESSURE PROCESSING FOR FOODS PRESERVING

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ABSTRACT

Consumers have a growing preference for convenient, fresh-like, healthy, minimal-processed food products with natural flavor and taste and extended shelf-live. High pressure processing (HPP) is a promising "non-thermal" technique for food preservation that efficiently inactivates the vegetative microorganisms, most commonly related to food-borne diseases allowing most foods to be preserved with minimal effect on taste, texture or nutritional characteristics. The main advantage of high pressure processing compared to thermal sterilization and pasteurization is maintenance of sensory and nutritional characteristic of treated food products. HPP provides a means for retaining food quality while avoiding the need for excessive thermal treatments or chemical preservation. High-pressure processing provides a unique opportunity for food processors to develop a new generation of value-added food products having superior quality and shelf-life to those produced conventionally.

Biotechnol. & Biotechnol. Eq. 2010, **24**(3), 1940-1945

Keywords: high pressure processing, foods, non-thermal preservation

Abbreviations used: high pressure processing: HPP

Introduction

Consumers have a growing preference for convenient, fresh-like, healthy, minimal-processed food products with natural flavor and taste and extended shelf-live. To match these demands without compromising safety, in the last decade alternative not-thermal preservation technologies as high pressure processing (HPP), irradiation, light pulses, natural bio-preservatives together with active packaging have been proposed and further investigated (2).

High pressure processing is a promising "non-thermal" technique for food preservation that efficiently inactivates the vegetative microorganisms, most commonly related to food-borne diseases. High pressure processing is carried out with intense pressure in the range of 100-1000 MPa, with or without heat, allowing most foods to be preserved with minimal effect on taste, texture or nutritional characteristics. The main advantage of high pressure processing compared to thermal sterilization and pasteurization is maintenance of sensory and nutritional characteristic of treated food products (3).

Pressure treatment can be used to process both liquid and high-moisture-content solid foods. Pressure processing is a lethal to microorganisms but at relatively low temperatures (0-40°C) covalent bonds are almost unaffected. The limited effect of HPP (at moderate temperature) on covalent bonds represents a unique characteristic of this technology because HPP has a minimal effect on food chemistry (4). HPP provides a means for retaining food quality while avoiding the need for excessive thermal treatments or chemical preservation (2).

Microbial inactivation is one of the main goals for the application of high pressure technology. The inactivation effect of high pressure processing results in extending shelf-life and improving the microbial safety of food products. According to some researches high pressure treatment could be accepted as a food safety intervention for eliminating *Listeria monocytogenes* in processed meat products and cheese (19, 47). Hydrostatic pressure treatment is also effective in inactivating other hazardous microorganisms such as *E. coli*, *Salmonella*, and *Vibrio*, as well as many yeasts, molds, and bacteria responsible for food spoilage. The microbiological shelf-life and food quality can be substantially extended by the use of HPP (23, 24).

Bacterial spores represent a challenge for high pressure technology and more information about their resistance is required. Microbial spores suspended in foods or laboratory model system could be inactivated by high pressure treatment but compared to vegetative cells the treatment conditions must be extreme: higher pressure and long exposure time at elevated temperature (28). When pressure-temperature is combined at 690 MPa and 80°C for 20 minutes, the treatments was effective with a significant reduction in the *Clostridium sporogenes* spore count (13). Successful treatment of *Bacillus stearothermophilus* is observed were pressure treatments is combined with moderate temperature (70°C) (22). There are no published reports on the high-pressure resistance of *Clostridium botulinum* spores, and their ability to withstand high pressure at low or high temperatures is unknown (35).

Pressure treatment can also be used to alter the functional and sensory properties of various food components, especially proteins. The tertiary and quaternary structures of molecules which are maintained mainly by hydrophobic and ionic interactions are beneficially altered by high pressure above 200 MPa (25). The hydrophobic and electrostatic interactions are most affected but not the hydrogen bonds which stabilize α-helical and ß-pleated sheets (27). Meat, fish, egg and dairy proteins can be denatured with HPP in the absence of elevated temperatures. Increased viscosity and opacity are obtained with little change in fresh flavour. On the other hand, high pressure has very little effect on low-molecular-weight compounds such as flavour compounds, vitamins, and pigments compared to thermal processes. Accordingly, the quality of HPP pasteurized food is very similar to that of fresh food products. The quality throughout shelf-life is influenced more by subsequent distribution and storage temperatures and the barrier properties of the packaging rather than by the high pressure treatments (6, 7).

Basic High Pressure Processing Principles

High-Pressure technology has been cited as one of the best innovations in food processing from the last 50 years. Some physical and chemical changes result from application of pressure. Physical compression during pressure treatment results in a volume reduction and an increase in temperature and energy (27).

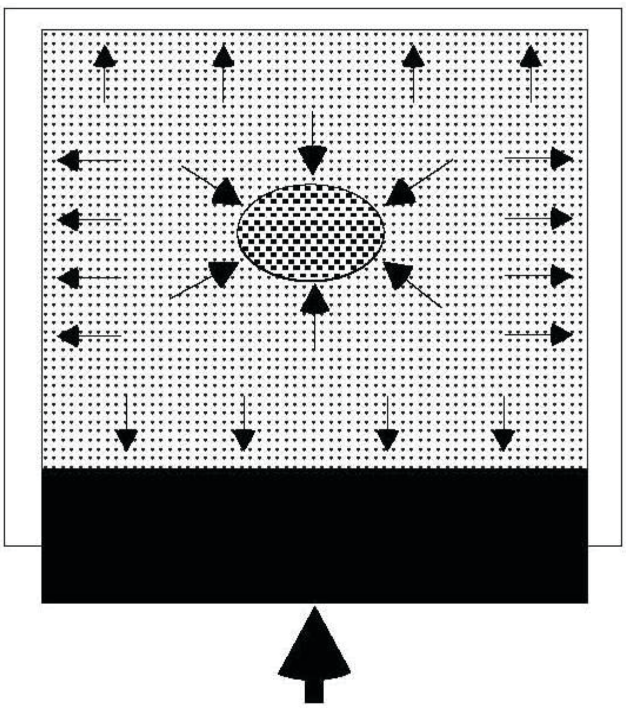

Fig. 1. The principle of isostatic processing (40)

The basic principles that determine the behavior of foods under pressure are:

- **Le Chatelier's principle**: any reaction, conformational change, phase transition, accompanied by a decrease in volume is enhanced by pressure (12, 20, 36);

- **principle of microscopic ordering**: at constant temperature, an increase in pressure increases the degrees of ordering of molecules of a given substance. Therefore pressure and temperature exert antagonistic forces on molecular structure and chemical reactions (4);

- **isostatic principle**: the principle of isostatic processing is presented in **Fig. 1**. The food products are compressed by uniform pressure from every direction and then returned to their original shape when the pressure is released (40). The products are compressed independently of the product size and geometry because transmission of pressure to the core is not mass/time dependant thus the process is minimized (12, 20, 36).

If a food product contains sufficient moisture, pressure will not damage the product at the macroscopic levels as long as the pressure is applied uniformly in all directions (13).

High Pressure Equipment

Even if the principles of HPP and its influence on microbial inactivation have been recognized since late 1800's, the first commercial installation for HPP appeared in Japan in 1990 (4, 48). Although high pressure technology is currently more expensive than traditional processing technologies, the use of high pressure offers new opportunities for food industry to respond to the demand from consumers (25, 26).

A high-pressure system consists of a high-pressure vessel and its closure(s) pressure-generation system, temperature-control device and material-handling system (37). The pressure vessel is the most important component of high-hydrostatic-pressure equipment. Several aspects must be taken into account in vessel design. It is necessary to design the high-pressure vessel to be dimensionally stable in a safe-fail way. If it fails it should fail with leak before fracture (14). Pressure-transmitting fluids are used in the vessel to transmit pressure uniformly and instantaneously to the products sample. Most widely used fluids are water, glycol solutions, silicone oil, sodium benzoate solutions, ethanol solutions, inert gases and castor oil (48). The food products should be packaged in a flexible packaging. The packages are loaded into the high pressure chamber. The vessel is sealed and the vessel filled with pressure transmitting agent. The high pressure is usually carried out with water as a hydraulic fluid to facilitate the operation and compatibility with food materials (17). The basis for applying high pressure to foods is to compress the water surrounding the food. At room temperature, the volume of water decreases with an increase in pressure. Because liquid compression results in a small volume change, high-pressure vessels using water do not present the same operating hazards as vessels using compressed gases (18). Ones the desired pressure is reached the pump or piston is stopped, the valves are closed and the pressure can be maintained without further energy input. After holding the product for the desired time at the target pressure, the vessel is decompressed by releasing the pressure-transmitting fluid (20). For most applications, products are held for 3-5 min at 600 MPa. Approximately 5-6 cycles per hour are possible, allowing time for compression, holding, de-compression, loading and unloading. After pressure treatment, the processed product is removed from the vessel and stored in a conventional way (1).

High pressures can be generated by direct or indirect compression or by heating the pressure fluid (15).

Direct compression

It is generated by pressurizing a fluid by a piston, driven at its larger diameter end by a low pressure pump (**Fig. 2**). This method allows very fast compression, but the limitations of the high-pressure dynamic seal between the piston and the vessel's internal surface restrict the use of this method to small-diameter laboratory or pilot plant systems.

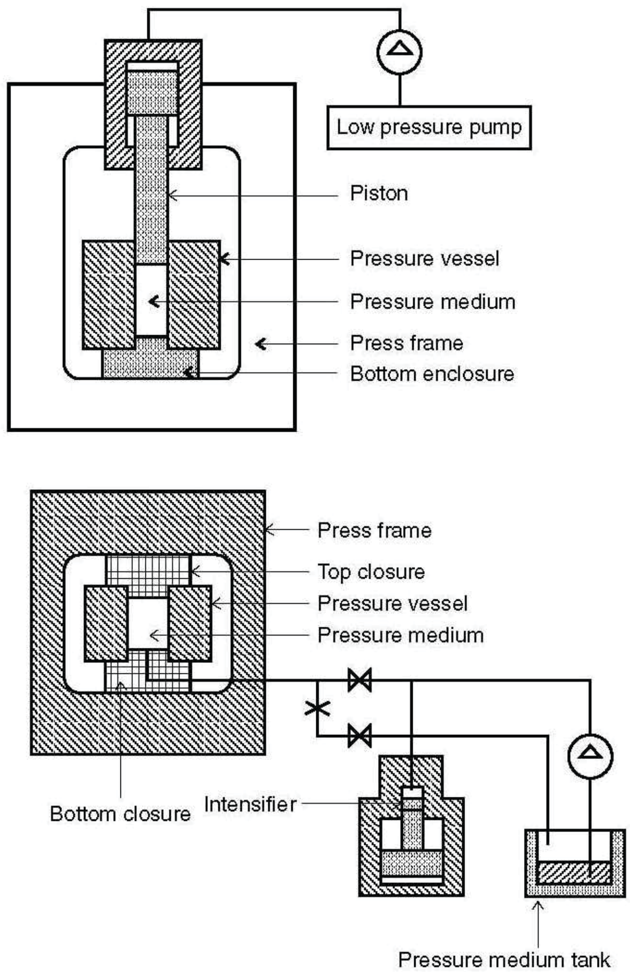

Fig. 2. Generation of high pressure by direct (top) and indirect (bottom) compression of the pressure-transmitting medium (37)

Indirect compression

This technique uses a high-pressure intensifier to pump a pressure medium from a reservoir into a closed high-pressure vessel until the desired pressure is reached (**Fig. 2**).

Heating of the pressure medium

It utilizes expansion of the pressure fluid with increasing temperature to generate high pressure. This method is therefore used when high pressure is applied in combination with high temperature and requires very accurate temperature control within the entire internal volume of the pressure vessel (5).

Pressure-Temperature Effect

To understand and foresee the effect of HPP on foods it is necessary to take in attention the net combined pressure-temperature effect on the treated foods.

During the compression phase (t_1-t_2) of pressure treatment food products undergo a decrease in volume as a function of the pressure (**Fig. 3**). The product is held under pressure for a certain time (t_2-t_3) before decompression (t_3-t_4). Upon decompression, the product will usually expand back to its initial volume (18). The compression and decompression can result in a transient temperature change in the product during treatment. The temperature of food (T_1-T_2) increases as a result of physical compression (P_1-P_2). Product temperature (T_2-T_3) at process pressure (P_2-P_3) is independent of compression rate as long as heat exchange between the product and the surroundings is negligible. In a perfectly insulated (adiabatic) system, the product will return to its initial temperature upon decompression (P_3-P_4). In practice, however, the product will return to a temperature (T_4) slightly lower than its initial temperature (T_1) as a result of heat losses during the compression phase. The rapid heating and cooling resulting from HPP treatment offer a unique way to increase the temperature of the product only during the treatment and to cool it rapidly thereafter. The temperature of water increases about 3^{o}C for every 100 MPa of increased pressure at room temperature. On the other hand, fats and oils have a heat of compression value of 8-9^{o}C/100 MPa, and proteins and carbohydrates have intermediate heat of compression values (41, 44).

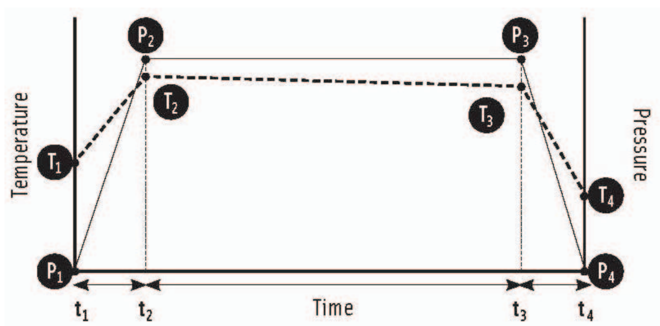

Fig. 3. Pressure-temperature history during high pressure processing (3, 41, 44)

High Pressure Processing and Microbial inactivation

Microbial inactivation is one of the main goals for the application of high pressure technology.

The extent of microbial inactivation that is achieved by suitable high pressure treatment depends on a number of interacting factors, including type and number of microorganisms, magnitude and duration of high pressure treatments, temperature and composition of the suspension media or food (2).

The pressure sensitivity of microorganisms may vary between species and probably among the strains of the same species. Microorganisms can be divided into those that are relatively pressure sensitive and those that are pressure resistant. Generally Gram-positive bacteria are more resistant to pressure than Gram-negative bacteria, moulds and yeasts. Most resistant to high hydrostatic pressure are bacterial spores. The sensitivity of microbial cells depends on the stage of the growth cycle at which the organisms are subjected to high hydrostatic pressure treatment. In general, cells in the exponential phase are more sensitive to pressure treatments than cells in the log or stationary phases of growth (16, 42). The grater resistance to pressure when the cell metabolism is slowed down may be due to accumulation of cell components that reduce the effect of high pressure (31). Rich nutrient media such as meat reinforce the resistance of the microorganisms to HPP. Carbohydrates, proteins and lipids also have a protective effect (35). A low water activity protects microorganisms against pressure and tends to inhibit pressure inactivation with noticeable retardation as water activity falls below 0.95 (46).

The extent and duration of high pressure treatment influence the microbial inactivation. An increase in pressure increases microbial inactivation. However, the duration of treatment is increased that does not necessary leads to an increase in the lethal effect. As mentioned above, the microbial response to high-pressure treatments depends on the type of microorganism. For each of them, there is a pressure-level threshold beyond which no effects are detected by increasing the exposure time. There also exists a pressure level at which increasing the treatment time causes significant reductions in the initially inoculated microbial counts.

The temperature during high pressure treatment influences the range of inactivation of microbial cells. Some authors showed that the pressure resistance of microbial organisms is maximal at temperature 15-30^{o}C and decreases significantly at higher or lower temperature (10, 11, 12).

The treatment of microbial cell and spores with high pressure results in many changes in the morphology, cell membranes, biochemical aspects and genetic mechanisms and all these processes are related to the inactivation of microorganisms. The lethal effect of high pressure on vegetative microorganisms is thought to be the result of a number of possible changes that take place simultaneously in the microbial cell.

The membrane is the most probable site of disruption (29). High-hydrostatic pressure treatments can alter membrane functionalities such as active transport or passive permeability and therefore perturb the physicochemical balance of the cell (43). There is a considerably evidence that pressure tends to loosen the contact between attached enzymes and membrane surface as a consequence of the changes in the physical state of lipids that control enzyme activity. The leakage of intracellular constituent through the permeabilized cell membrane is the most direct reason for cell death after high pressure treatment (27).

Inactivation of key enzymes, including those involved in DNA replication and transcription is also mentioned as a possible inactivating mechanism (29).

Bacterial spores have demonstrated pressure resistance and the mechanisms through which they are inactivated are different from these for the vegetative cells. It has been suggested that the spore proteins are protected against solvation and ionization (21, 45). Microbial spores could be inactivated by chosen suitable conditions for high pressure treatment: higher pressure and long exposure time at elevated temperature (21). It was assumed that pressure caused inactivation of spores by first initiating germination and then inactivating germinated forms. The spore germination could be induced by hydrostatic pressure of 100-300 MPa and resultant vegetative cells are sensitive to environmental conditions (33, 34).

Usually for pasteurization purpose the considered treatment is generally in the range of 300-600 MPa for a short period of time, from seconds to minutes, inactivating vegetative pathogenic and spoilage microorganisms. For sterilization the range is over 600 MPa and combination with high temperature is needed because some spores are resistant even to pressure over than 1000 MPa when the temperature is not higher than 45-75^{o}C (12). Most yeast are inactivated by exposure to 300-400 MPa at 25^{o}C within a few minutes, however, yeast ascospores may require treatment at higher pressure. Pressure inactivation of moulds follows a model similar to yeast (46).

To explain the response of microorganisms to different pressure, high-pressure effects on several biological molecules have been studied. Protein denaturation, lipid phase change and enzyme inactivation can perturb the cell morphology, genetic mechanisms, and biochemical reactions. However, the mechanisms that damage the cells are still not fully understood (43).

Aspects of Applications of High Pressure Processing of Foods

High-pressure processing provides a unique opportunity for food processors to develop a new generation of value-added food products having superior quality and shelf-life to those produced conventionally.

High pressure processing is a very promising technology for ready-to-eat (RTE) meats because there are few barriers to approval by regulatory authorities, no special labelling requirements because no chemicals are added, and if used appropriately there are no changes to texture or flavour of the product. Researchers found that in RTE meats that are pressure treated at 600 MPa at 20°C for 180 sec, there were no changes in sensory quality, no difference in consumer acceptability, a 4 log reduction in *Listeria monocytogenes* in inoculated product and the refrigerated shelf-life was extended (23). There is report that HPP treatment (600 MPa for 10 minutes at 30°C) could extend the shelf-life of food including cooked ham, dry cured ham and marinated beef loins (30). High pressure application of 500 MPa could extends the shelf life of cooked pork ham and raw smoked pork loin up to 8 weeks, ensuring good microbiological and sensory quality of products (19).

High pressure processing can effectively inactivate the spoilage microorganisms of several foods, and important food-borne pathogens such as *Campylobacter jejuni*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella spp*. Foods can be pasteurized at low or moderate temperatures under pressure. Pressurization at high temperature can sterilize foods. Pressure treatment is of special interest for products or meals containing ingredients that are extensively modified by heat (32).

HPP has potential as a phyto sanitary treatment to control quarantine insect pests in fresh or minimal processed fruits and vegetables to extend their shelf-life (7, 38). Pressure inactivation of yeast and moulds has been reported in citrus juices. Juices pressurized at 400 MPa for 10 min at 40^{o}C did not spoil during 2-3 months of storage (39, 40). The high pressure treatment effectively reduced the bacterial flora of fresh goat milk cheese and significantly extended the refrigeration storage life No surviving *E. coli* was detected in cheese after 60 days of storage (2-4^{o}C) in inoculation studies after treatments at 400-500 MPa for 5-10 min (9).

High-pressure technology could improve the microbiological safety and quality of foods, including meat, milk, and dairy products.

Conclusions

High pressure technology proposes a great potential to develop new “minimally” treated foods with high nutritional and sensory quality, novel texture and with an increased shelf-life.

The novelty of HPP technology and high equipment costs are barriers to its commercialization but increased consumer’s demand for fresher-tasting foods containing fewer preservatives drives an increase in this segment. HPP can preserve food products without heat treatment or chemical preservatives, and its ability to ensure safety and significantly extended refrigerated shelf life has opened new market opportunities particularly in the area of “natural” preservative free food products.

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