Chapter 14

Non-thermal processing of fishes

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Food processing involves the transformation of raw materials into consumer-ready products, with the objective of stabilizing them to prevent negative changes in quality and ensure food safety. To consumers, the most important attributes of a food product are its sensory characteristics like texture, flavour, aroma, shape and colour. The aim of food manufacturers is to develop and employ processing technologies that retain or create desirable sensory qualities or reduce undesirable changes which take place during processing. Alternative or novel food processing technologies are being explored and implemented to provide safe, fresher-tasting, nutritive foods without the use of heat or chemical preservatives. The major non thermal technologies gaining importance are High-pressure processing, Pulsed light technology, Pulsed electric field, Irradiation etc.

High pressure processing

The application of very high pressures (upto 87,000 psi, 6000 bar or 600 MPa) for preservation of food substances in combination with or without heat is known as high pressure processing (HPP). This process is also known as high hydrostatic pressure processing (HHP) or ultra-high pressure processing (UHP). When compared to thermal processing, pressure treated foods have a fresher taste, better appearance, texture and nutritional value. High pressure processing can be conducted at ambient or refrigerated temperatures, thereby eliminating thermal effects and cooked off-flavors. The technology is highly beneficial for heat sensitive products. The first high pressure processing line was introduced in Japan for jam manufacture in 1990's and has since been upgraded to several food products. A number of HPP products have been commercialized in North America, Europe and in China. Machines are now available with operating pressures in the range 400-700 MPa and capacities ranging up to 900 kg per batch. Since HP processing affect mainly the non-covalent bonds of the food, the quality characteristics of foods such as color, flavor and nutrients generally remain unaffected (Knorr, 1993).

Principles of High Pressure Processing

The two main principles of direct relevance to the use of high pressures in foods are the Le Chatelier's Principle and the Isostatic Principle. Le Chatelier's applies to all physical processes, and states that when a system at equilibrium is disturbed the system responds in a way that tends to minimize the disturbance (Pauling, 1964). This means that HP stimulates reactions that result in a decrease in volume but opposes reactions that involve in an increase in volume. Any phenomenon (e.g. phase transition, change in molecular configuration, chemical reaction) that is accompanied by a decrease in volume will be enhanced by pressure. Secondly, the Isostatic rule states that pressure is instantaneously and uniformly transmitted throughout a sample under pressure whether the sample is in direct contact with the pressure medium or hermetically sealed in a flexible package that transmits pressure (Olsson, 1995). Pressure is transmitted in a uniform (isostatic) manner throughout the sample; the time necessary for pressure processing is therefore independent of sample size, in contrast to thermal processing.

Mechanism of Pressure Treatment

Each processing cycle consists of an initial pressurization period where the pressure builds up and the processing is undertaken with or without application of heat to the product. The food product to be treated is packed in a flexible or semi flexible container or pouch and placed in a pressure vessel capable of sustaining the required pressure. The product is submerged in pressure-transmitting medium, which is a liquid. Water is commonly used as the pressure-transmitting medium. Other liquids include castor oil, silicone oil, sodium benzoate, ethanol or glycol etc in various combinations with water or separately. The pressure-transmitting fluid should be able to protect the inner vessel from corrosion and liquids base on the manufacturer's specification is usually used. The process temperature range and the viscosity of the fluid under pressure are some of the factors involved in selecting the medium. The hydraulic fluid is pressurized with a pump, and this pressure is transmitted uniformly throughout the packaged food. High pressure processing is independent of size and geometry of the food and acts instantaneously, thereby reducing the total processing time. The process is most suitable for liquid foods and solids which contain a certain amount of moisture. Since the pressure is transmitted uniformly and simultaneously in all directions, food retains its shape even at extreme pressures. Once the pressure is build up to the desired level the product is held at this pressure for a few minutes and then decompression or pressure release takes place. Once there is a fall in pressure the product temperature falls below that of the initial product temperature. During the pressurization process adiabatic heating takes place and there is an increase in the temperature of the food product which is again dependent on the pressure transmitting fluid, product, pressurization rate, temperature and pressure. In the case of water the increase in temperature due to adiabatic heating is 3°C for every 100 MPa increase in pressure.

Major Advantages of the Technology

1. It does not break covalent bonds; therefore, the development of flavours unacceptable to the product quality is prevented and the natural qualities of products are maintained.
2. It can be applied at room temperature thus reducing the amount of thermal energy needed for food products during conventional processing.
3. Since High pressure processing is isostatic (uniform throughout the food), the food is preserved evenly throughout without any particlcs escaping the treatment.
4. High pressure is not time-mass dependent i.e. it acts instantaneously thus reducing the processing time.
5. High pressure processing is independent of size and geometry of the food.
6. The process is environment friendly since it requires only electric energy and there are no waste products.

Applications in Marine Products

Sea foods are highly perishable and usually spoil faster than other muscle foods. They are more vulnerable to post-mortem changes when compared to meat or any other animal product. Fish is characterized by the presence of odourless compounds called Trimethylamine oxide (TMAO) which on spoilage is converted to trimethyl amine by bacterial enzymes, and is used as the assessment of quality. Generally volatile bases are produced in fish muscle by autolytic enzymes, putrefactive micro-organisms or by chemical reactions. High pressure processing can play a vital role in reducing the microbial load and thereby maintaining the quality of the product without bringing about any changes in the raw product.

HPP can be applied in a wide area of fish processing. HPP can be used to extend the shelf life of products. It can be used to eliminate pathogens like *E. coli, Salmonella* and *Listeria* and spoilage bacteria without affecting color and flavor of the product. HPP can be used to develop new gel based products with desired sensory attributes and mouth feel. HPP is used worldwide in shell fish processing for 100 % removal of meat from the shells and for reducing the microbial risks during raw seafood consumption. The application of high pressure processing in muscle foods is either for tenderization of the muscle or for extension of shelf life. This process inactivates vegetative microorganisms and reducing the bacterial contaminations and the pathogens (Ohshsima et al., 1993). High pressure can be used to modify functional properties of the food material while simultaneously enhancing safety of raw seafood's and retaining its sensory and nutritional qualities. High pressure promotes increased shelf life without affecting, chemical, microbiological, and sensory characteristics while inactivating pathogens inherent in the product. Since the processing is usually done at low or moderate temperatures, this does not affect the covalent bonds, but disrupts secondary and tertiary bonds and reduces the enzymatic activity and thereby minimize loss in flavor bearing components (Torres & Velazquez, 2005). High pressure treatment in combination with salting and smoking are reported to extend the shelf life of different types of products (Montero et al., 2007) and the combination of high pressure and short treatment was found effective in improving the quality of smoked salmon (Gudbjornsdottir et al., 2010). Applications for marination and impregnation of desired flavors and colors can also be effectively undertaken. Pressure assisted thermal processing for development of shelf stable ready to eat products is another promising area of research. Pressure assisted freezing and pressure assisted thawing helps in retaining the microstructure and reduce drip loss in fish products.

Seafood is a highly perishable commodity and technologies like high pressure processing are essential to increase the market value of some high value fishes. High pressure processing has a growing demand in the global market. A lot of studies are being done on HPP from the past decade. Further studies on the effects of this technology on the biochemical characteristics and microflora of shellfish are necessary. The effectiveness of high pressure on microbial and enzyme inactivation, while maintaining optimal product quality is a crucial factor for the commercialization of the technology. HP processing offers many advantages over conventional processing methods known to seafood. This is exemplified by the success of HP-processed oysters in USA by Motivatit Seafood, Goose Point Oysters and Joey Oysters. However, as HP processing becomes more widely available, initial capital costs may be reduced, making technology accessible to more producers. In addition, the commercialization of the technology for other foods may provide encouragement for seafood processors, by allaying apprehension regarding the use of this novel technology and demonstrating consumer acceptance of HP-processed products (Fig. 1.).

Pulsed light technology

Pulsed light (PL) is an emerging non-thermal technology for decontamination of food surfaces and food packages, consisting of short time high-peak pulses of broad-spectrum white light (Dunn et al., 1989). The term light is generally used to mean radiations having wavelength ranging from 180 to 1100 nm, which includes ultraviolet rays (UV 180–400 nm, roughly subdivided into UV-A, 315–400 nm; UV-B, 280–315 nm; UV-C, 180–280 nm); visible light (400–700 nm) and infrared rays (IR 700–1100 nm). (Palmieri and Cacace, 2005). Pulsed light is produced using technologies that multiply power manifold. It is used for the rapid inactivation of microorganisms on food surfaces, equipment, and food packaging materials (Dunn et al., 1995). The effect on microorganisms is mostly due to the photochemical action of the ultra violet part of the light spectrum that causes thymine dimerization in the DNA chain preventing replication and ultimately leading to cell death (Gomez-Lopez et al., 2007).

Pulsed light is a modified and claimed improved version of delivering UV-C to bodies. The classical UV-C treatment works in a continuous mode, called continuous-wave (CW) UV light. Inactivation of microorganisms with CW-UV systems is achieved by using low-pressure mercury lamps designed to produce energy at 254 nm (monochromatic light), called germicidal light (Bintsiset al., 2000). More recently, medium-pressure UV lamps have been used because of their much higher germicidal UV power per unit length. Medium-pressure UV lamps emit a polychromatic output, including germicidal wavelengths from 200 to 300 nm (Bolton & Linden, 2003). PL treatment of foods has been approved by the FDA (1996) under the code 21CFR179.41 (Fig. 2.).

Generation of Pulsed Light

Light can be emitted from different sources by different mechanisms, due to the spontaneous transition of some atoms from an excited state to a condition of lower energy. Light can be delivered either continuously or in the form of pulses. (Palmieri and Cacace, 2005). Pulsed light works with Xenon lamps that can produce several flashes per second. During the pulse treatment the spectrum produced is 20000 times brighter than sunlight at the surface of the earth (Dunn et al., 1995). Electromagnetic energy is accumulated in a capacitor during fractions of a second and then released in the form of light within a short time (nanoseconds to milliseconds), resulting in an amplification of power with a minimum of additional energy consumption. As the current passes through the gas chamber of the lamp unit, a short, intense burst of light is emitted. The light produced by the lamp includes broad-spectrum wavelengths from UV to near infrared. The wavelength distribution ranges from 100 to 1,100 nm.

Merits and Demerits

Merits

The inactivation of microbes by PL is very fast process and cause rapid disinfection in a very short period. It is a green technology as the consumption of energy is very less during its application. It has been proven as a safe technology for living being and their environment without producing harmful residuals, chemicals and toxic by-products in the PL treated foods. It does not affect the nutritional and sensory quality of the products. The concerns of ionized radicals and radioactive by-products in foods by consumers are removed in PL due to its nonionizing spectrum (Dunn et al.1995).

Demerits

PL application in meat industry has some constraints as the low penetration power and chances of lipid oxidation (Fine &Gervais, 2004). To get the desired outcome, the packaging materials showing high penetration of PL should be used while treating the packed food by this method. The limited control of food heating still remains the main concern in PL technology. Sample heating is perhaps the most important limiting factor of PL for practical applications (Gomez-Lopez et al., 2007).

Irradiation

Irradiation is the process of applying low levels of radiation to any food material to sterilize or extend its shelf life. It is a physical method that involves exposing the prepackaged or bulk foodstuffs to gamma rays, x-rays, or electrons. Foods is generally irradiated with gamma radiation from a radioisotope source, or with electrons or x-rays generated using an electron accelerator (Barbosa-Canovas et al., 1998). These rays have high penetration power and thus can treat foods for the purpose of preservation and quality improvement. During exposure of food the amount of ionizing radiation absorbed is termed 'radiation absorbed dose' (rad) and is measured in units of rads or Grays. A strictly regulated process of dosimetry is used to measure the exact dose of radiation absorbed by the food. One Gray is equal to one joule of energy absorption per kilogram of a material. Irradiation has been approved for the microbial disinfestations of various food products in the US (USFDA, 1998). A number of countries worldwide have irradiated products in the markets. Irradiation has the potential to enhance food safety for fresh foods that will be consumed raw and for raw foods that require further processing. Food irradiation mainly is done by the radioactive element cobalt-60 as the source of high energy gamma rays. Gamma rays are electromagnetic waves or photons emitted from the nucleus of an atom. These gamma rays have energy to dislodge electrons from food molecules, and to convert them into ions which are electrically charged. However, the rays do not have enough energy to dislodge the neutrons in the nuclei of these molecules and hence they are not capable of inducing radioactivity in the treated food. The radiation dose varies depending on the thickness moisture, and characteristics of the foods. External factors, such as temperature, the presence or absence of oxygen, and subsequent storage conditions, also influence the effectiveness of radiation (Doyle, 1990).

Applications of Irradiation

In general, irradiation of food does not significantly affect the protein, lipid, and carbohydrate quality. Minerals are stable to food irradiation. The overall chemical changes in food due to irradiation are relatively minor and hence there is little change in the nutritional quality. Irradiation of moist food under frozen condition and in the absence of oxygen significantly decreases the overall chemical yields by about 80%; so the cumulative effects of irradiating to a dose of 50 kGy at −30°C is essentially equivalent to a dose of 10 kGy at room or chilled temperature. A dose of 1-10 kGy has can control food-borne parasites responsible for diseases such as trichinosis, A minimum dose of 0.15 kGy can prevent development of insects in dried fish. Irradiation is considered as a phytosanitary measure often obligatory if certain agricultural commodities are to be exported . The unique feature of radiation decontamination is that it can be performed in packaged foods even when the food is in a frozen state (Fig. 3.). Table I gives details of irradiation processes for seafoods.

Table 1: Radiation processes of seafoods (*Source:* Venugopal, Protech 2013-Pg28)

Treatment and storage temperature	**Radiation process**	**Benefits**
-10° to -20°C Packaged, frozen, ready-to-export fish can be treated before shipment. Frozen storage	Radicidation (Radiation hygienization) Dose required: 4-6 kGy Elimination of non-spore forming pathogens such as *Salmonella, Vibrio, Listeria* etc.	Improvement of hygienic quality of frozen, materials for export such as frozen shrimp, cuttlefish, squid, finfish, fillets, and IQF items.
15° to 30°C Ambient storage	Radiation disinfestation Dose required < 1 kGy Elimination of eggs and larvae of insects.	Dry products free from spoilage due to insects, from dried fishery products including fish meal and feed for aquaculture. Inactivation of *Salmonella* spp. and other pathogens
-1°to +3°C (Post-irradiation storage: under ice).	Radurization (Radiation pasteurization for shelf life extension) Dose: 1-3 kGy Reduction of initial microbial content by 1 to 2 log cycles. Specific reduction of spoilage causing organisms.	Extends chilled shelf life of fresh marine and freshwater fishery products two to three times. Additional benefit includes reduction of non-spore forming pathogens

Pulsed electric field

Pulsed electric field processing is a non-thermal food preservation technique used mainly for inactivation of microbes. PEF technology involves the application of short pulses of high voltage to liquid or semi-solid foods placed between two electrodes. Most PEF studies have focused on PEF treatments effects on the microbial inactivation in milk, milk products, egg products, juice and other liquid foods. The pulsed electric field induces poration of cell membranes and thereby the cell membranes of microorganisms, plant or animal tissue are permeable. This process of electroporation is suitable for use in a broad range of food processes and bioprocesses using low levels of energy. PEF technology has many advantageous in comparison to heat treatments, because it kills microorganisms and at the same time maintains the original color, flavor, texture, and nutritional value of the unprocessed food (Fig. 4.).

Pulsed Electric Field Preservation (*Source:* i³ foods)

Pulsed electric field can be applied in fishes fresh and frozen fish dried, brined or marinated fish. Mass transport processes, such as moisture transport and removal, are improved by the electroporation of fish tissue, resulting in enhanced drying, brining and marinating of fish. The required field strength for cell disintegration of fish is 1,0 – 3,0 kV/cm and the energy delivery is 3 – 10 kJ/kg The applied pulsed electric field leads to cell disintegration in tissue, enhancing product quality and production processes. It also helps in inactivation of parasites such as nematodes. PEF processing enhances mass transport, processes during extraction, pressing, drying, brining and marinating processes.PEF technology speeds up drying of food products, minimizing processing times and energy consumption. The process can be applied to fruits, vegetables, potatoes and meat. Enhancement of extraction processes is also an advantage of electroporation. Extraction and pressing yields are increased, for example for fruit juice, vegetable oil and algae oil and protein. PEF technology speeds up freezing of food products, allowing a reduction of processing times and energy consumption. The cell disintegration increases the freezing rates. Cellular water flows easily out of the cell and ice nucleation outside the cell starts. As smaller ice molecules are formed, product quality of frozen food is improved. (www. pulsemaster).

Fig. 1.High Pressure Processing Facility at ICAR-CIFT

A Research model 2 litre capacity High Pressure machine from M/s Stansted Fluid Power Ltd, United Kingdom at Central Institute of Fisheries Technology, Cochin.

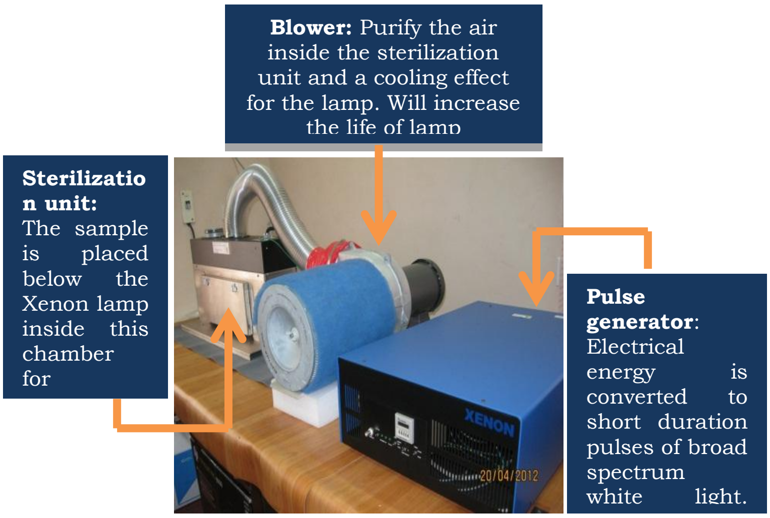

Fig.2 Pulse light equipment at CIFT

Fig.3 Applications of irradiation

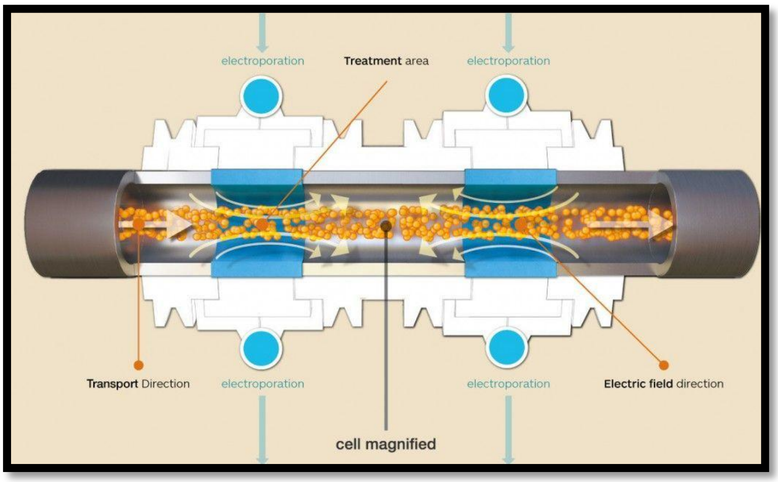

Fig.4 Pulsed electric field

Further reading

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