Next Generation Trends in Food Processing

K. S. Kadiya and A. H. Jana
Department of Dairy Technology, SMC College of Dairy Science, AAU, Anand-388110.
E-mail: kunalkadiya@aau.in

Technical Articles

Although thermal preservation provides safe food, it may incur loss of food properties like nutrients and sensory attributes. The main objectives in adopting newer non-thermal processing techniques are to retain the nutrients, sensory properties and to increase the shelf life. The main objective of food preservation is to increase its shelf life by reducing the microbial load and perhaps the water activity. Both can be achieved by either traditional method of preservation or by non-thermal treatments like microwave heating, Pulsed Electric Field (PEF), High Pressure Processing (HPP), Pulsed Light Technology, Ohmic heating, Irradiation, Ultrasonics, Pulsed X-Rays, Oscillating Magnetic Fields (OMF) and Cold plasma techniques. The selection of a particular preservation method for specific food application is based on cost and scale of production, type of product (milk, meat, poultry, vegetables, etc.), shelf life and end product usage. This paper deals with various non-thermal processing of food, its working mechanism and its application in the food processing industries.

High Pressure Processing

HPP is also known as "High Hydrostatic Pressure" or "Ultra High Pressure" processing. HPP uses up to 900 MPa to kill many of the microorganisms found in foods, even at room temperature without degrading vitamins, flavour and colour. When high pressures (up to 1000 MPa) are applied to packages of food that are submerged in a liquid, the pressure is distributed instantly and uniformly throughout the food (isostatic). Typically a pressure of 350 MPa applied for 30 min or 400 MPa for 5 min will cause a 10-fold reduction in vegetative cells of bacteria, yeasts or moulds. HPP does not involve "heating or cooling" periods and there is a rapid "pressurization/depressurization" cycle, thus reducing processing times compared to thermal processing. Enzymes that are related to food quality vary in their barosensitivity (Cano *et al.,* 1997).

Equipment for HPP

HPP unit consists of a 'pressure vessel' and a 'pressure generating device'. Other components include temperature control device and materials handling system. Food packages are loaded onto the vessel and the top is closed. The pressure medium, usually water, is pumped into the vessel. Once the desired pressure is reached, the pumping is stopped, valves are closed and pressure is maintained. The principle underlying HPP is that high pressure is applied in an "isostatic" manner such that all regions of food experience uniform pressure, unlike heat processing where temperature gradients are established.

Pressures of greater than 400 MPa was required to cause >50% denaturation of whey protein (Beresford *et al.*, 1998). Use of HPP employing 50 MPa at 25°C for 3 days was reported to accelerate the ripening of Cheddar cheese. A treatment of 400 MPa at 20°C resulted in significant inhibition of microorganisms. A 3 log reduction in case of bacterial species and 6 log for *Penicillium* mould was noted. The Gram positive *S. aureus* species was more resistant to pressure than the Gram negative *E. coli* species. Though the mould species were more resistant than bacteria at low (< 300 MPa) pressures, the former were much more sensitive at higher pressures.

Applications of HPP

HPP kills vegetative bacteria and spores and the processing time is reduced; there is no evidence of toxicity. Freshness, flavour, nutrients, colour and taste of the treated product are retained.

Uniformity of treatment throughout the food is achieved and use of chemical preservatives can be avoided. In pack processing is possible and energy consumption is low.

HPP has been used for pasteurization and sterilization of fruits and fruit products, sauces, pickles, yoghurt, pasteurization of meat and vegetables, decontamination of high risk products, and sterilization of heat sensitive products like shellfish, flavorings, and vitamins.

In dairy products, HPP is used to manufacture niche products (yogurt, dairy desserts and smoothies) to control syneresis, produce a firmer texture, increase shelf life, improve the texture and accelerate ageing of cheese and enhance safety of raw milk cheese. HPP when combined with cold pasteurization helps in maintaining the bioactivity of probiotics and of the molecules of milk, colostrum and whey.

Pulsed Electric Field

Pulsed Electric Field (PEF) is a non-thermal food preservation technology that involves the discharge of high voltage electric pulses (up to 70 kV/cm) to the food product, which is placed between two electrodes for a few microseconds (Sensoy *et al*., 1997; Angersbach *et al*., 2000; Picart and Cheftel, 2003). An external electric field is used to exceed a critical transmembrane potential of 1 volt. This results in rapid conformational changes in the cell membranes that lead to release of intracellular liquid and subsequent cell death. However, treatment temperature should be kept low in order to avoid heat damage to the product and to prevent off-flavours. PEF treatment at 50kV/cm for 2000ms inactivated 45% of papain activity. The loss of the catalytic activity was counted on the changes in loss of α-helix in papain secondary structure (Yeom *et al*.,1999). In orange juice PEF treatment at 35 kV/cm for 590 ms was good when compared with those of heat pasteurization at 94.6°C for 30 seconds (Yeom *et al*., 2000).

The typical components of PEF equipment include

Power supply: this may be an ordinary direct current power supply or a capacitor charging power supply (this latter option can provide higher repetition rates).

Energy storage element: this can be either electric (capacitive) or magnetic (inductive).

Switch: Either for closing or opening. Devices suitable for use as the discharge switch include a mercury ignitron spark gap, a gas spark gap, thyratron, a series of Switch Circuit diode, a magnetic switch or a mechanical rotary switch.

Pulse shaping and triggering circuit in some cases.

Treatment chamber: in wide variety of designs.
Pump: to supply a feed of product to the chamber.

Cooling system to control the temperature of the feed and/or output material.

Mechanism of microbial inactivation

Electrical Breakdown: The membrane can be considered as a capacitor filled with a dielectric. The normal resisting potential difference across the membrane is 10 mV and leads to the build-up of a membrane potential difference due to charge separation across the membrane. Potential difference is proportional to the field strength and radius of the bacterial cell. The increase in the membrane potential leads to reduction in the cell membrane thickness.

Electroporation: It is the phenomenon in which a cell exposed to high voltage electric field pulses, temporarily destabilizes the lipid bilayer and proteins of cell membranes. The plasma membranes of cells become permeable to small molecules and permeation causes swelling and rupture of the cell membrane.

Applications of PEF Technology

PEF is used in processing of milk, processing of apple juice, orange juice, liquid whole eggs, baking applications and processing of green pea soup. PEF deactivates natural microflora and permits to use lower pasteurization temperature while improving the shelf life of pasteurized liquids. The activity of milk's bioactive molecules (lactoferrin, lactoperoxidase, immunoglobulin) are therefore preserved and the stability of certain proteins is improved.

Pulsed Light/High Intensity Light Technology

High intensity light is described as pulsed broad spectrum white light, which is a decontamination or sterilization technology that can be used for rapid inactivation of microorganisms on food surfaces, equipments and food packaging materials. Surface decontamination of food products using pulsed high intensity light (PHIL) is of significance to the food industry. It is a non-thermal preservation intervention. High intensity white light and UV light food preservation methods employ light wave lengths ranging from ultra violet to near infra-red, in short intense pulse. Pulses of light used for food processing applications typically emit 1 to 20 flashes of electromagnetic energy. Sauer and Moraru (2009) achieved a 7.15 log cfu reduction of *Escherichia coli* in apple juice, using a dose of up to 12 light pulses. Gómez-López *et al.* (2005) achieved 0.5–2.04 log reduction in mesophilic, aerobic microbes naturally found in minimally processed vegetables (spinach, iceberg lettuce, cabbage, celeriac, soybean sprouts, etc.) using a dose of up to 2.7 light pulses. The decontamination of bulk tank milk with pulsed UV light was investigated by Smith *et al.* (2002) and it was found that the bacterial content of milk can be adequately controlled by non-thermally (cold) pasteurize bovine milk exposed to Pulsed UV laser light.

Process and Equipment for PHIL

The principle involved in generating high intensity light is a gradual increase of low to moderate power energy that can be released in highly concentrated bursts of more powerful energy. The key component of a Pulsed Light unit is a flash lamp which is filled with an inert gas (i.e. xenon) which emits broadband radiation that ranges from the UV cut off of the envelope material (~180 nm) to near Infra red (~1100 nm). A high-voltage, high-current electrical pulse is applied to the inert gas in the lamp, and the strong collision between electrons and gas molecules excites the latter, which then emit an intense, very short light pulse (1 μs to 0.1 s). UV light is thought to play a critical role in microbial inactivation. The antimicrobial effects of UV light on bacteria are attributed to structural changes in the DNA, as well as abnormal ion flow, increased cell membrane permeability and depolarization of the cell membrane. There are injurious effects on yeast cells and mould spores upon exposure to Pulsed Light.

The main limitation of PHIL is its limited penetration depth. Since the effectiveness of Pulsed Light is strongly influenced by the interaction of the substrate with the incident light, the treatment is most effective on smooth, non-reflecting surfaces or in liquids that are free of suspended particulates. In surface treatments, rough surfaces hinder inactivation due to cell hiding, while for very smooth surfaces surface reflectivity and cell clumping caused by hydrophobic effects are also limits the degree of microbial reduction. PHIL treatment to be effective, it is necessary to ensure uniform, 360° exposure of the treated food.

Applications of PHIL: PHIL is used for decontamination of vegetables and even dairy products. Such treatment is also used for microbial inactivation of water, sanitation of packaging materials and disinfection of equipment surfaces.

Pulsed X-Rays

Pulsed X-ray is a technology that utilizes a solid state opening switch to generate electron beam x-ray pulses of high intensity. Electrons have limited penetration depth of about 5cm in food, while x-ray have significantly higher penetration depths (60-400 cm) depending upon the energy used. Curry *et al.* (1999) used a system comprising of an x-ray accelerator with a thyristor charging unit, a magnetic pulse compressor, a solid state opening switch, an electron beam diode load and an x-ray converter. The thyristor charging unit converts 3-phase current to direct current. A thyristor capacitor charging circuit is used to charge the magnetic pulse compressor. A 2-stage circuit compresses and steps up the voltage pulse before it is used to charge an inductive load. Energy from capacitor is transferred from the inductive load in ~100 ns. A converter is installed on the accelerator and the electron beam is converted to pulsed x-rays to allow thick samples to be processed.

Applications: Pulsed X-rays are used for the inactivation of *E. coli* in meat, and to eliminate Salmonella from foods.

Microwave Heating

Microwave heating refers to the use of electromagnetic waves of certain frequencies to generate heat in material. For food applications most commonly used microwave frequencies are 2450MHz and 915MHz. When a microwavable container with food is placed in a microwave oven, a temperature gradient develops between the centre and the edges. Meat, fish, fruit, butter and other foodstuffs can be tempered from cold store temperature to around -3ºC for ease of further processing (i.e. grinding of meat in production of burgers, blending and portioning of butter packs). Food products, such as bread, precooked foods have been processed using microwaves for pasteurisation or sterilisation or simply to improve their digestibility.

Mechanism of microwave processing

Dipolar Interaction: Once microwave energy is absorbed, polar molecules such as water molecules inside the food will rotate according to the alternating electromagnetic field. The water molecule is a 'dipole' with one positively charged end and one negatively charged end. Similar to the action of magnet, these 'dipoles' will orient themselves when they are subject to electromagnetic field. The rotation of water molecules would generate heat for cooking.

Ionic Interaction: In addition to the dipole water molecules, ionic compounds (i.e. dissolved salts) in food can also be accelerated by the electromagnetic field and collides with other molecules to produce heat.

The microwave oven generally consists of the following basic components.

Power supply and control: It controls the power to be fed to the magnetron as well as the cooking time.

Magnetron: It is a vacuum tube in which electrical energy is converted to an oscillating electromagnetic field.

Waveguide: It is a rectangular metal tube which directs the microwaves generated from the magnetron to the cooking cavity. It helps in preventing direct exposure of the magnetron to any spattered food which would interfere with the function of the magnetron.

Stirrer: It is commonly used to distribute microwaves from the waveguide allowing more uniform heating of food.

Turntable: It rotates the food product through the fixed hot and cold spots inside the cooking cavity and allows the food to be evenly exposed to microwaves.

Cooking cavity: It is a space inside which the food is heated when exposed to microwaves.

Door and choke*:* This allows the access of food to the cooking cavity. The door and choke are specially engineered so that they prevent microwaves from leaking through the gap between the door and the cooking cavity.

Materials for microwave heating

Plastic containers are commonly used for microwave cooking. High density polyethylene can be used for foods with high water content, it cannot be used for foods with high fat or high sugar content as these foods. Paper and board can absorb some microwave energy. However, it is not ideal for microwaved food because the strength of the paper would be affected when wet. When food is microwaved, heat is also retained in the glass. The degree of energy absorption depends on the type of glass. Moreover, microwave energy can be superimposed at the centre after passing through the glass containers, particularly the ones with small radius.

Applications of microwave: Microwave is used in baking, concentration, cooking, curing, drying, finish drying, pasteurizing, sterilizing, tempering, thawing and freeze drying (as adjunct process).

Ohmic Heating

Ohmic heating is based on the principle of passing an electric current through an electrically conducting product; electric energy is transformed into heat. Ohmic heating is an efficient way of processing foods containing large solid particulates unlike conventional method of processes such as canning and aseptic processing. After heating, the products can be cooled in continuous heat exchangers and then aseptically filled into sanitized containers in a manner similar to conventional aseptic packaging. Both high and low acid food products can be processed by this method. The type of food suitable for ohmic heating depends on the product's electrical conductivity and whether the product is an insulator or a conductor. Through use of ohmic heating, simultaneous and uniform heating of solid and liquid phases can be achieved, thus reducing the danger of under processing as well as nutritional loss. The critical parameters affecting ohmic heating include the electrical conductivity of the food, temperature dependence of electrical conductivity, the design of heating device, the residence time, distribution time, thermo-physical properties of foods and the electric field strength.

At 25°C, the electrical conductivity of pineapple was very low and significantly different than that of apples and pear. Electrical conductivity of peach and strawberry was high. The gap in the electrical conductivity between strawberry and peach, and other fruits increased with the temperature (Sanjay, 2007). Cloudberry jam was treated with ohmic heating and also by traditional method. There was no significant difference in the sensory attributes and rheological properties of Cloudberry jam subjected to ohmic heating compared to traditional heating method (Lindbom *et al*., 2006).

Applications of ohmic heating: Such treatment is used in blanching, evaporation, dehydration, fermentation, extraction and value added process.

Ultrasonics

The frequency of sound waves audible to human ear ranges from 20 Hz to 200 kHz. The sound waves having frequencies > 20 kHz are called 'Ultrasonics' or 'Supersonics'. Sound waves of frequencies < 20 Hz are called 'Infrasonics'. Application of power ultrasound is of significance in ice cream since it helps in reducing ice crystal size and prevents incrustation on freezing surface (Zheng and Sun, 2006).

Production of Ultrasonics

Mechanical Method: This is the earliest method for producing Ultrasonic waves of frequencies up to 100 kHz with the help of Galton's Whistle. This is rarely used due to its limited range.

Piezoelectric Generator: Crystal is placed between two metal plates. This combination forms a parallel plate condenser with crystal as dielectric. The metal plates are connected to the primary of a transformer which is coupled to the oscillatory circuit of the triode valve. If the natural frequency of the oscillatory circuit of triode valve coincides with the crystal frequency, resonance will occur and the crystal is set into the mechanical vibrations due to piezoelectric effect. With a quartz crystal ultrasonics frequency of 5, 40,000 Hz can be produced. To produce higher frequencies the plate has to be very thin and strong so that it may stand strain. Tourmaline crystal may be used to generate frequencies up to 1.5 x 10^8 Hz.

Magneto-striction Generator: A bar of ferromagnetic material like iron or nickel changes in its length when it is placed in a strong magnetic field applied parallel to its length. A nickel rod is placed at a rapidly varying magnetic field that alternately expands and contracts with twice the frequency of the applied magnetic field. This change in length of the ferromagnetic material is independent of the polarity of applied magnetic field. The longitudinal expansion and contraction in ferromagnetic rod produces ultrasonic sound waves in the medium surrounding the nickel rod. The frequency of ultrasonics produced ranges from 8000 Hz to 20000 Hz.

Applications: Ultrasonics is used for pasteurization at mild heat, extraction, enzyme inactivation, emulsification and also used as a processing aid including the mixing materials; foam formation or destruction; agglomeration and precipitation of air borne powders; the improvement in efficiency of filtration, drying and extraction techniques in solid materials and the enhanced extraction of valuable compounds from vegetables and food products. Ultrasonic can be a specialized and versatile technology with numerous applications in food processing.

Cold Plasma

Cold plasma is a novel non-thermal food processing technology that uses energetic, reactive gases to inactivate contaminating microbes on meats, poultry, fruits, and vegetables. This flexible sanitizing method uses electricity and a carrier gas, such as air, oxygen, nitrogen, or helium; antimicrobial chemical agents are not required. The primary modes of action are due to UV light and reactive chemical products of the cold plasma ionization process (Niemira, 2012). A wide array of cold plasma systems that operate at atmospheric pressures or in low pressure treatment chambers are under development. Reductions of greater than 5 logs can be obtained for pathogens such as *Salmonella, Escherichia coli O157:H7, Listeria monocytogenes, and Staphylococcus aureus*. Effective treatment times can range from 120 s to as little as 3s, depending on the food treated and the processing conditions. Key limitations for cold plasma are the relatively early state of technology development, the variety and complexity of the necessary equipment, and the largely unexplored impacts of cold plasma treatment on the sensory and nutritional qualities of treated foods.

Overview of Methods of Cold Plasma Generation

Cold plasma discharges can be produced by a variety of means, some of which have been the subject of research since the earliest years of inquiry into electrical phenomena (Becker *et al.*, 2005). There are three basic forms of cold plasma discharge systems. The glow discharge has electrodes at either end of a separating space, which may be partially evacuated or filled with a specific gas. The radio frequency discharge uses pulsed electricity to generate cold plasma within the centre of the electrical coil. The barrier discharge uses an intervening material with high electrical resistance (the dielectric material) to distribute the flow of current and generate the plasma. A simple form of the barrier discharge systems is shown; these systems may use one or two layers of dielectric material, arranged in various configurations. These may also be arranged in an annular or tubular form, with one electrode entirely within the other. In those designs, the cold plasma is generated in the space between the electrodes. These designs allow for gas movement across the zone of plasma generation and delivery of the cold plasma to the target.

Action of Plasma on microorganisms

The reactive species in plasma have been widely associated to the direct oxidative effects on the outer surface of microbial cells. As an example, commonly used oxygen and nitrogen gas plasma are excellent sources of reactive oxygen-based and nitrogen-based species, such as O•, O2, O3, OH•, NO•, NO2 etc. Atomic oxygen is potentially a very effective sterilizing agent, with a chemical rate constant for oxidation at room temperature of about 106 times that of molecular oxygen (Critzer *et al.*, 2007). These act on the unsaturated fatty acids of the lipid bilayer of the cell membrane, thereby impeding the transport of bio-molecules across it. The double bonds of unsaturated lipids are particularly vulnerable to ozone attack (Guzel-Seydim *et al*,. 2004). Membrane lipids are assumed to be more significantly affected by the reactive oxygen species (ROS) due to their location along the surface of bacterial cell, which allows them to be bombarded by these strong oxidizing agents (Montie *et al.*, 2002). The proteins of the cells and the spores are equally vulnerable to the action of these species, causing denaturation and cell leakage. Oxidation of amino acids and nucleic acids may also cause changes that result in microbial death or injury (Critzer *et al.*, 2007).

Application of Cold Plasma

Cold plasma can be used to coat the surface of foods (dairy or non-dairy) with a film of vitamins or sensitive bioactive compounds. Equally known as the fourth state of matter, cold plasma can be used to disinfect, but it does not penetrate deeply. It effectively disinfects the irregular surfaces of equipment and packaging.

Conclusion

The major problem with thermal processing of food is loss of volatile compounds, nutrients, and flavour. To overcome these problems non-thermal methods are being increasingly adopted by the food industries. The non-thermal processing of foods aids in attaining food products of better quality, acceptance, and with adequate shelf life too. These new processing techniques are mostly employed for liquid packed foods as against solid foods. Since the non-thermal methods are used for bulk quantities of foods, these methods of food preservation are mainly used in large scale production. However, the cost of equipments used to impart non-thermal processing is high as compared to equipments being used for conventional thermal processing.

References

Angersbach A, Heinz Vand Knorr D. (2000).Effects of pulsed electric fields on cell membranes in real food systems. *Innovative Food Sci& Emerging Technol*, 1:135-149.

Becker KH, Kogelschatz U, Schoenbach KH, Barker RJ. (2005). Generation of cold plasmas. In: Non-equilibrium Air Plasma at Atmospheric Pressure. Becker KH, Kogelschatz U,Schoenbach KH, Barker RJ (Eds.), Inst. Phys Pub, Bristol, UK, pp. 19–24.

Beresford TP, Reilly O, Connor O, Murphy,PMand Kelly A. (1998). Acceleration of cheese ripening: current technologies, potential use of high pressure. *Proc. VTT Symposium*, Helsnki, Finland 186: 103-114.

Cano MP, Hernandez A and De Ancos B. (1997). High pressure and temperature effects on enzyme inactivation in strawberry and orange products.*J Food Sci,* 62:85-93.

CritzerF, Kelly-Wintenberg K, South S and Golden D. (2007). Atmospheric plasma inactivation of foodborne pathogens on fresh produce surfaces. *J Food Protec,*70:2290.

CurryR, UnklesbayN, Clevenger.T, BrazosB, MesyatsG and FilatovA. (1999).The effect of high doses rate x-rays on*E-coli* O157:H7 in ground beef.*IEEE on Plasma Science*, 28:122-127.

Gómez-López VM, Devlieghere F, Bonduelle V and Debevere J. (2005).Intense light pulses decontamination of minimally processed vegetables and their shelf-life. *IntJ Food Microb*, 103:79-89.

Guzel-Seydim ZB, Greene AK and Seydim AC. (2004). Use of ozone in the food industry. *Lebensmittel-Wissenschaftund-Technologie*, 37:453-460.

Lindbom I, Kerry J, Nunes H, Pereira R, Sousa Gallagher MJ, Staruch L, Teixeira JA, Wendin K, Vicente A.(2006). Ohmic heating in a food application-quality evaluation of cloudberry jam.33rd International conference of Slovak Society of Chemical Engineering,TatranskeMatliare, Slovakia. 22-26 May, 2006. ISBN 80-227-2409-2.

Montie TC, Kelly-Wintenberg K and Roth JR. (2002). An overview of research using the one atmosphere uniform glow discharge plasma (OAUGDP) for sterilization of surfaces and materials. *Plasma SciIEEE Transactions*, 28:41-50.

Niemira BA. (2012). Cold plasma decontamination of foods. *Annual Rev Food SciTechnol*, 3: 125-142.

Picart L, Cheftel JC. (2003). Pulsed electric fields. In: Zeuthen P, Bogh-Sorensen L, editors. Food preservation techniques. CRC Press, pp. 57–68.

Sanjay S. (2007).Ohmic heating for thermal processing of low acid foods containing solid particulates. Dissertation work in Ph.D, Ohio State University, Ohio, https://etd.ohiolink.edu/!etd.send_file?accession=osu1197669208&disposition=inline.

Sauer A and Moraru CI. (2009). Inactivation of *Escherichia coli* ATCC 25922 and *Escherichia coli* O157:H7 in apple juice and apple cider, using pulsed light treatment. *J. Food Protect*, 72: 937-944.

Sensoy I, Zhang QH and Sastry SK. (1997). Inactivation kinetic of *Salmonella dublin* by pulsed electric fields. *J. Food Proc. Engg*, 20: 367–381.

SmithWL, Lagunas-solar MC and Cullor JS. (2002).Use of pulsed ultraviolet laser light for the cold pasteurization of bovine milk. *J Food Protec,* 65:1480-1482.

Yeom HW, Streaker CB, Zhang QH and Min DB.(2000). Effects of pulsed electric fields on the quality of orange juice and comparison with heat pasteurization. *J. Agric. Food Chem,* 48: 4597-4605.

Yeom HW, Zhang QH and Dunne CP. (1999). Inactivation of papain by pulsed electric fields in a continuous system. *Food Chem*, 64:53-59.

Zheng L and Sun DW. (2006).Innovative applications of power ultrasound during food freezing processes – a review. *Trends Food Sci. Technol*, 17:16-23.