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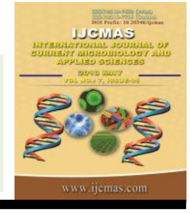

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An Elementary Review on Principles and Applications of Modern Non-Conventional Food Processing Technologies

Sheshrao Kautkar[1*] and Jai Prakash Pandey[2]

[1]Department of FM&PHT, ICAR-Indian Grassland and Fodder Research Institute, Uttar Pradesh-284003, India
[2]Department of PHP&FE, G. B. Pant University of Agriculture and Technology, Uttarakhand-263145, India

**Corresponding author*

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A B S T R A C T

Post-harvest processing and value addition is the most important aspect related to all the food products. Processing of agricultural commodities means converting the raw food material in to consumer acceptable form with increased shelf life and maintained nutritional quality. It can be achieved through various conventional food processing methods like drying, dehydration, evaporation, extrusion, freezing etc. The main lacunae with these conventional methods are loss of colour, flavour, vitamins and other nutrients due to higher temperature and longer processing time. These methods also causes problems like fouling on heating surface, energy inefficiency and emission of combustion gases in to the atmosphere leading to atmospheric pollution. The non-conventional food processing technologies like ohmic heating, microwave heating, ultrasound, pulsed electric field and high pressure processing are modern processing and preservation methods, rising as green technologies in food processing sector which represents environmental impact in terms of energy efficiency, water savings and reduced pollution. These technologies can produce high quality products with improvements in terms of heating efficiency, energy savings, reduced time and processing costs. All these technologies have wide range of applications in food industry like pasteurization, sterilization, oil extraction, juice extraction, clarification, filtration, cooking, baking, blanching, evaporation, drying, and dehydration. A comprehensive review is made to study the working principles, equipments, applications, advantages and limitations of these processing methods for used in various food product development and preservation operations.

Introduction

In the modern era of food quality, safety, security and global warming, the responsibility is there on the shoulder of food processing industries to produce the food which satisfies consumer needs with keeping environment intact. The conventional thermal processing methods, such as pasteurization, sterilization, drying and evaporation, are still used in food industries to process the raw agricultural commodity. These traditional methods depend on the generation of large amount of heat outside the product to be heated, by combustion of fuels or by an electric heated. These methods degrade the nutritional value of the product because of large extent of heat. Also considerable losses of heat on the surfaces of the equipment and installations, reduces the heat transfer efficiency of the processing method. Therefore in order to maintain food quality, microbial safety, to increase working life of equipments and heat transfer efficiency and to reduce atmospheric pollution we have to adapt some modern food processing technologies that can efficiently replace the conventional thermal food processing methods (Vicente and Castro, 2007). Ohmic heating and microwave heating are emerging alternatives to conventional methods of heat processing which generate heat directly inside the food products without using any external heating surface. These methods maintain nutritional quality of the product, reduces processing time with increased energy and heating efficiency than conventional methods. Now days, non-thermal technologies such as ultrasounds, high pressure processing, pulsed electric fields and pulsed light treatment have also been utilized for manufacturing of food products. These technologies has the ability to inactivate microorganisms, spores, enzymes and bacteria's at reduced temperatures and hence preserves the sensory and nutritional quality of products (Stoica *et al.,* 2013). A comprehensive review is made to provide the basic information of these modern non-conventional thermal and non-thermal technologies in order to understand their working principles, equipments, applications, advantages and limitations.

Ohmic heating (OH)

Principle of ohmic heating

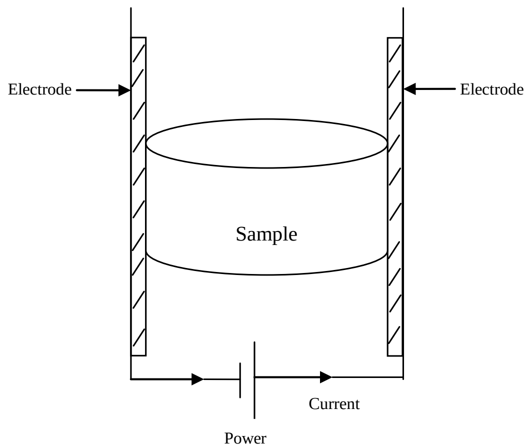
Ohmic heating is also called as "electrical resistance heating", "joule heating", or electro conductive heating" (Varghese *et al.,* 2012). It is a simple food processing technique in which alternating electric current (AC) is passed through liquid or liquid-particulates foods primarily for heating. Heat generation is based on the principle that most food products have the ability to resist to the passage of an electrical current due to the electrical resistance of the food products. AC voltage is applied to the electrodes at both ends of the product body as shown in Figure 1 which cause internal energy generation within the food material. The most important factor in OH is electrical conductivity (EC) which is materials ability of how efficiently it flow electric current through it (Sakr and Liu, 2014) and its temperature dependence (Legrand *et al.,* 2007). The EC is the ratio of the current density to the electric field strength and its SI unit is Siemens per meter (S/m). It increases with increasing temperature, which means OH becomes more effective as temperature increases (Kautkar *et al.,* 2015). Absence of any external heating part makes it useful to avoid the thermal degradation of the product and keeps products quality basically intact.

Equipment and applications

The main components of OH system consist of electrodes, heating chamber and AC supply as shown in Figure 1 (Kautkar *et al.,* 2016). It consists of other accessories like lid, control panel, stand, and voltmeter and ampere meter. The heart of OH system is two stainless steel electrodes and the function of these electrodes is to pass the electric current from the source of power supply to the food to be heated, the heating chamber is the place where food product is kept for heating, alternating current power supply is given to provide current to the system. This technology has wide range of applications in processing and used by various researchers for rice bran stabilization and oil extraction (Lakkakula *et al.,* 2004), blanching (Icier *et al.,* 2006), dehydration, evaporation (Assiry, 2011), juice extraction, peeling

(Ngasri and Sastry, 2016), thawing (Duygu and Umit, 2015) fermentation, sterilization, pasteurization etc. (Knirsch *et al.*, 2010; Kautkar *et al.*, 2014).

Fig.1 Ohmic heating



Advantages and limitations

OH has many advantages to be used in the food industries like uniform heating, high energy efficiency, reduced risks of fouling of heat transfer surface and burning of the food, higher temperature in shorter time can be achieved, suitable for both batch as well as continuous process, no residual heat transfer after the current is shut off, ease of process control with instant switch-on and shut-down and eco-friendly processing (Sakr and Liu, 2014). Limiting factors of using OH consist of unsuitability for solid or dry foods and requirement voltage adjustments according to the electrical conductivity of the foods.

Microwave heating

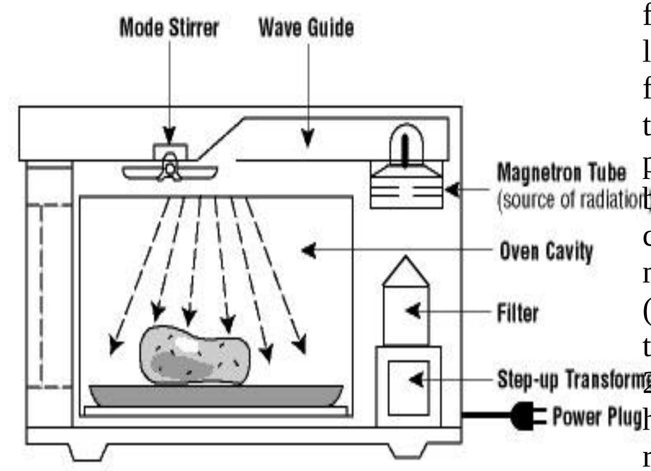
Principle of microwave heating

Microwaves are electromagnetic waves which have frequency range between 300 MHz and 3000 MHz corresponding to wavelength from 1 mm to 1 m. Microwave frequencies of 915 MHz and 2450 MHz can be utilized for industrial, scientific, and medical applications (Bradshaw *et al.*, 1998). Food products have water molecules inside them which are dipolar in nature with one positively charged and other negatively charged end. These dipoles will orient themselves when they are subject to electromagnetic field. Once microwave energy is absorbed by food material, polar molecules such as water will rotate according to the alternating electromagnetic field. The rotation of water molecules is very rapid and about 24 billion times per second (Hill and Ilsi, 1998). This rapid orientation and reorientation of water molecule causes huge friction and hence a high amount of heat is generated inside of product. In addition to the dipole water molecules, ionic compounds (i.e. dissolved salts) in food can also be accelerated by the electromagnetic field and collided with other molecules to produce heat (Buffler, 1993).

Equipment and applications

The microwave heating system mainly consists of magnetron, wave guide, microwave cavity, fan, stirrer and turntable as shown in Figure 2. The magnetron is a diode-type electron tube which generates required 2450 MHz of microwaves. Microwave cavity is a space inside which the food is kept for heating. Waveguide is the passage used to pass the microwaves from magnetron to cavity. The function of stirrer and turntable is to pass the microwaves to each corner of cavity and to rotate the food so that microwaves can uniformly apply on it (Puligundla *et al.*, 2013). Microwaves have numerous applications in food processing which includes sterilization, pasteurization (Al-Hilphy and Ali, 2013), drying (Lule and Koyunchu, 2015), blanching (Ramesh *et al.*, 2002), baking (Al-Muhtaseb *et al.*, 2013), cooking (Zhang and Hamauzu, 2004), thawing, boiling etc.

Fig.2 Microwave heating



Advantages and limitations

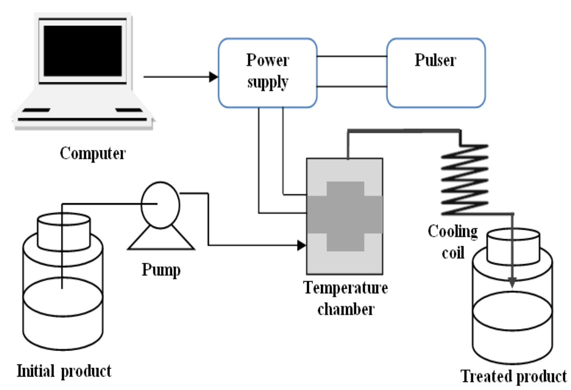
Microwave heating possesses many advantages which include rapid and uniform heating, high heating efficiency i.e. 80% of the energy can be converted into heat, reduced loss of nutrients, minimum fouling depositions, suitable for heat-sensitive, high-viscous, and multiphase fluids, do not generates exhaust gases therefore food does not contaminates by products of combustion, equipment is small, compact, clean in operation and automatic process control. Lower penetration depth, higher initial cost, non uniform heating when using large size product are some of the limitations of this method.

Pulsed electric field (PEF)

Principle of pulsed electric field

Pulsed electric field or "high intensity pulsed electric field" is a novel non thermal food processing method used to inactivate the deteriorative microorganisms with minimal effects on the nutritional, flavour and functional characteristics of food products. It is based on the application of pulses of high voltage typically 20– 80 kV/cm passed on the product placed between a pair of electrodes (Reddy and Penchalaraju, 2014). The large field intensities are achieved through storing a large amount of energy in a capacitor bank from a direct current power supply, which is then discharged in the form of high voltage pulses (Zhang *et al.*, 1995). The pulse caused by the discharge of electrical energy from the capacitor is allowed to flow through the food material for an extremely short period of time (1–100 µs) and can be conducted at moderate temperatures for less than 1 sec (Deeth *et al.*, 2007). When food is subjected to the electrical high-intensity pulses, several events, such as resistance heating, electrolysis and electroporation can occur contributing to the inactivation of microorganisms (Sitzmann, 1995).

Fig.3 Pulsed electric field



Equipment and applications

Typical PEF system consists of a high-voltage power supply, capacitors to store the charge, a discharge switch to release the charge to electrodes and a pump to force the liquid product from feed tank to treatment chamber as shown in Figure 3. The gap between two electrodes is called as the treatment gap. This technology is mainly used for preservation of pumpable fluid or semi-fluid foods and it has many applications in food industry for liquid foods which includes pasteurisation and extraction of fruit juices (Korma *et al.*, 2016), soups, liquid egg (Nieto *et al.*, 2003) and milk (Hawa *et al.*, 2011), decontamination of heat sensitive foods (Zhao *et al.*, 2008).

Advantages and limitations

This novel food processing method is widely used to kill vegetative cells, to preserve colour, flavour and nutrients of the product without any toxicity and to process the food in relatively short treatment time. The lacunae associated with this method are it is difficult to use with conductive materials, no effect on enzymes and spores, suitable for liquids or particles in liquids only and products of electrolysis may adversely affect foods.

High pressure processing (HPP)

Principle of high pressure processing

High pressure processing is also called as “ultra-high-pressure processing” (UHP) or “high-hydrostatic pressure processing” As the name suggests it utilizes high pressure to process the food product (Muntean *et al.*, 2016). This is a promising non-thermal method of food preservation which efficiently inactivates the vegetative microorganisms, most commonly related to food borne diseases (Elamin *et al.*, 2015). When high pressures, up to 1000 MPa are applied to food packages submerged in a liquid, the pressure is distributed rapidly and uniformly throughout the food. The high pressure causes destruction of microorganisms (Rendueles *et al.*, 2011). Vegetative microbial cells can be destroyed or deactivated by application of moderately high pressures in the range of 300-600 MPa. Typically, a pressure of 350 MPa applied for 30 min or 400 MPa applied for 5 min will cause a ten-fold reduction in vegetative cells of bacteria, yeasts or moulds (Hoover *et al.*, 1989). The principle behind this technology is that the high pressure is applied in an “isostatic” manner such that all regions of food experience a uniform pressure, unlike heat processing where temperature gradients are established.

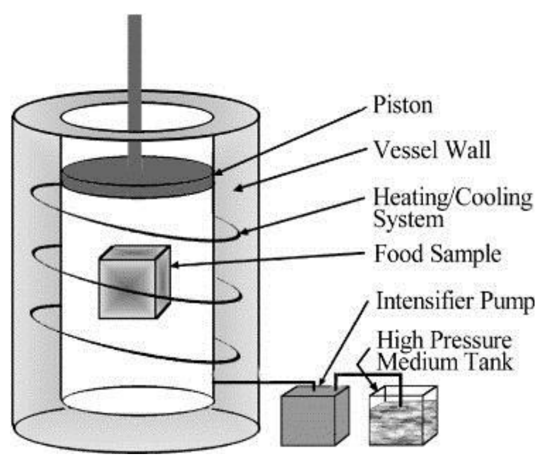
Equipment and applications

Typical HPP equipment consists of a pressure vessel, its closure, a pressure generating device, a temperature controlling device and materials handling system as shown in Figure 4 (Yordanov and Angelova, 2010). Food packages are submerged in to the vessel and the top is closed.

The pressure transmitting medium usually water is pumped into the vessel from the bottom. Once the desired pressure is achieved, the pumping is stopped, valves are closed and pressure can be maintained without further need for energy input.

HPP can effectively used in pasteurization and sterilization of fruits and vegetables (Hite *et al.*, 1914), milk (Hite, 1899), sauces, pickles, yoghurt, pasteurization of meat (Campus, 2010), decontamination of high risk products, high value products and sterilization of heat sensitive ingredients like shellfish, flavourings, and vitamins.

Fig.4 High pressure processing



Advantages and limitations

HPP is effective in killing vegetative bacteria and spores without generating any toxicity, maintains nutritional quality, reduced processing time, uniformity of treatment, in-package processing and it has potential for reduction or elimination of chemical preservatives. Some of the limitation of this method are it is the batch process and imparts little effect on enzyme activity, few microbial survival, expensive equipment and foods should have approximate 40% free water for anti-microbial effect.

Pulsed light technology

Principle pulsed light technology

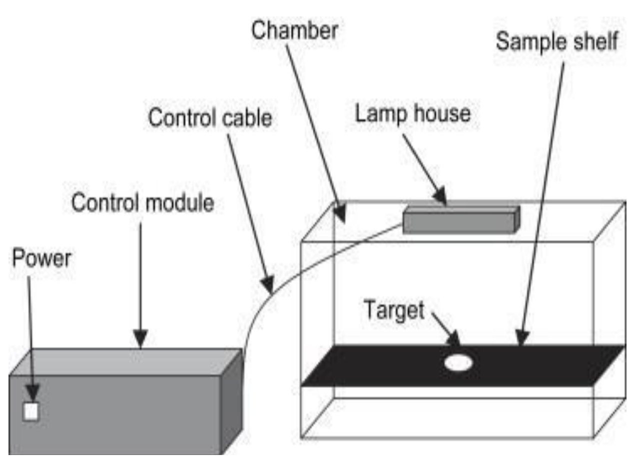
Pulse light technology (PL), also called as "high intensity light" is a non-thermal decontamination or sterilization method that can be used for rapid inactivation of microorganisms from food surfaces, equipments and packaging materials. It contains a broad spectrum of white light, from ultra violet (UV) wavelengths of 200 nm to infra-red (NIR) wavelengths of 1000 nm with peak emissions between 400–500 nm (Yasothai and Giriprasad, 2015). Pulses of light used for food processing applications typically emit 1-20 flashes per second of electromagnetic energy. The basic principle of light at UV wavelengths is its photochemical and/or photothermal effects (Elmanesser *et al.*, 2007; Gomez-Lopez *et al.*, 2007) which exhibits its antimicrobial nature.

The photochemical mechanism alters the structure of pyrimidine bases and DNA (Giese and Darby, 2000), leading to the death of the microorganisms (McDonald *et al.*, 2000). The photothermal effect is due to the conversion of UV photons into energy, causing a short, sharp, local temperature rise at the surface of the target (Whekof, 2000). When energy from UV wavelengths is absorbed by highly conjugated double carbon bonds in proteins and nucleic acids then several mechanisms like structural changes in the DNA, abnormal ion flow, increased cell membrane permeability and depolarization of the cell membrane occurs in the targeted material which leads to rapid inactivation of microorganisms (Abida *et al.*, 2014).

Equipment and applications

PL technology consists of a flash lamp, power supply unit and a treatment chamber as shown in Figure 5. The PL unit which is a flash lamp filled with an inert gas, such as Xenon, emits broadband radiation that ranges from the UV cut off to NIR **(**Dunn *et al.*, 1989) 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 cause excitation of the gas molecules, which then emit an intense, very short light pulse. This technology is used in decontamination of vegetables, dairy products (Yeom *et al.*, 2004), baked products, fruit beverages (Sharma *et al.*, 1998), meats and seafood's, drying and decontamination of, microbial inactivation of water, sanitation of packaging materials and disinfection of equipment surfaces (Abida *et al.*, 2014).

Fig.5 Pulsed light technology



Advantages and limitations

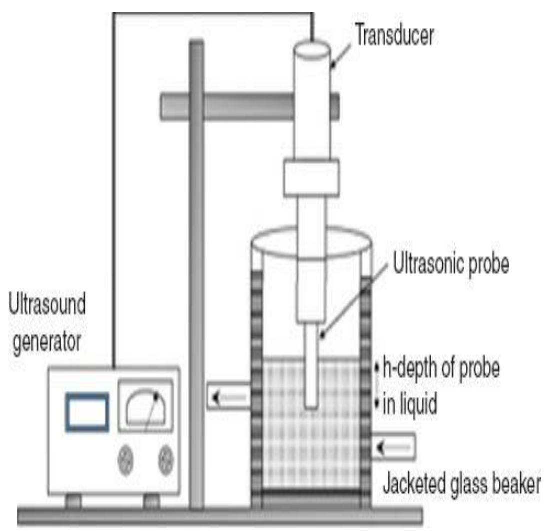
PL technology is relative fast method of food processing with little or no changes to food quality. It requires low energy input, suitable for dry foods, packaging materials and equipments. Apart from these advantages it has some limitations like only surface effects and therefore difficult to use with complex surfaces, not proven effective against spores, possible resistance in some microorganisms, reliability of equipment to be established and lower penetration depth.

Ultrasound

Principle of ultrasound

Sound is vibration that transmitted in a medium and can hear by human ear. The frequency of sound waves audible to human ear ranges from 16 Hz to 16-20 kHz (Chemat *et al.,* 2011). Sound waves of frequencies less than 20 Hz are called "Infrasounds" or "Infrasonic's" and the sound waves having frequencies greater than 20 kHz are called "Ultrasounds", "Ultrasonic's" or "Supersonic's". Ultrasounds are classified into two groups, low energy ultrasounds and high energy ultrasound. Low energy ultrasounds have the frequencies greater than 100 kHz, low power and low-intensity (<1 W/cm²). These are non-destructive, and uses small power that cannot cause physical or chemical alterations in the materials property and can used for providing information about physicochemical properties of foods like composition, structure and physical state of the food. High energy ultrasound on the other hand have the frequencies 18-100 kHz, high power and high-intensity (>1 W/cm²) (Villamiel and de Jong, 2000). These waves cause physical, mechanical or chemical effects on material and can be used for physical disruption and acceleration of chemical reactions (Awad *et al.,* 2012). When ultrasound waves meet a medium, it creates regions of alternating compression and expansion. These regions of pressure change cause cavitations i.e. formation of bubbles in the medium (Kentish and Feng, 2014). These bubbles are larger in size during the expansion cycle, which increases gas diffusion, causing the bubble to expand. When the ultrasonic energy is insufficient to retain the vapour phase in the bubbles then rapid condensation occurs. The condensed molecules collide and create shock waves. These shock waves create regions of high temperature and pressure. The ability of ultrasound to cause cavitations depends on ultrasound characteristics product properties ambient conditions (Patist and bates, 2008).

Fig.6 Ultrasound



Equipment and applications

The basic components of ultrasonic systems are power generator, transducer and reactor as shown in Figure 6. Power generator is nothing but the source of electrical power supply. The transducers are the devices used to convert electrical energy, coming from a power generator, into mechanical energy in the form of ultrasonic vibrations. The ultrasonic bath and probe are reactors. Ultrasound has wide applications in food industries which include mechanical, chemical and biochemical effects like crystallization (Chow *et al.,* 2003), defoaming, drying, freezing and tenderization of meat (Knorr *et al.,* 2004), extraction (Li *et al.,* 2004), degassing, filtration (Muthukumaran *et al.,* 2006), fermentation (Matsuura *et al.,* 1994), mixing, emulsification/homogenization (Freitas *et al.,* 2006), effluent treatment, enzyme and microbial inactivation, sterilization of equipments etc (Chemat *et al.,* 2011).

Advantages and limitations

Ultrasounds has many advantages in the processing of food which include its effectiveness against vegetative cells, spores and enzymes, reduced processing times and temperatures, little adaptation required of existing processing plant, increased heat transfer and can be both batch or continuous operation. The limitations of using ultrasound in processing sector are the depth of penetration is affected by solids and air in product, possible damage by free radicals, unwanted modification of food structure and texture may possible, sometimes need to be used in combination with another process like heat or pressure and potential problems with scaling-up plant.

Conventional thermal processing technologies, such as pasteurization, sterilization, drying and evaporation possess the problem of thermal degradation of the food leading to loss of volatile compounds, nutrients, colour, texture and flavour. These methods takes longer processing time therefore require high amount of fuel and energy and are also responsible for environmental pollution as they release combustion gasses by burning fuel during processing. To overcome these problems, modern non thermal processing methods are becoming popular in food industries to increase the production rate and profit. This review is made to study and understand the basic principle, equipments, applications, advantages and limitations of modern non-conventional food processing technologies. These technologies are suitable for processing of almost all the food products particularly for liquid and semi liquid foods and mainly suggested to be used in the large scale food production as they are economical for bulk quantities of foods. Initial cost of investment of these technologies is quit higher than conventional thermal processing methods therefore these technologies are not suited for small scale processing. Commercial adaptation of these technologies is very necessary to maintain nutritional and sensory quality of the product, to save fuel and energy, to avoid environmental pollution, to increase consumer appeal by improving product appearance, to reduce cost of processing, to ensure the availability of food throughout the year and to reduce post-harvest losses of agricultural commodities.

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