NEW TRENDS IN FOOD PROCESSING

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ABSTRACT

Preservation is the most important process related to all the food products. Preservation of food products can be achieved by various ways like addition of salt, sugars, preservatives, antioxidants, naturally occurring antimicrobial substances and also by the processes like drying, freezing, refrigerated storage and Hurdle Technology. Novel technologies like microwave heating, Pulsed Electric Field (PEF) Technology, High Pressure Processing (HPP), Pulsed Light Technology, Ohmic Heating, Ultra sonics, Pulsed X-Rays are also applied for the preservation of food products. The main problem with the thermal processing method is loss of colour, flavor, vitamins and other nutrients in food products. A detailed review is made for different non thermal processing methods and its merits and demerits are analyzed and illustrated for applications in various industries. This paper investigates different non thermal processing methods and its suitability to different food processing industries which deals with different foods like meat, milk, fish, egg and ready-to-eat foods.

KEYWORDS: *Non thermal, Preservation, HPP, PEF, SCF.*

I. INTRODUCTION

Although thermal preservation provides safer food, there exists loss of food properties like nutrients and sensory attributes. The main objectives of new techniques are, to retain the nutrients, sensory properties and to increase the shelf life without any adverse effect on its quality. The main objective of preservation is to increase the shelf life by reducing the microbial load and also the water activity. Both can be achieved by either traditional method of preservation methods or by non thermal treatments like microwave heating, Pulsed Electric Field (PEF) Technology, High Pressure Processing (HPP), Pulsed Light Technology, Ohmic Heating, Irradiation, Ultra sonics, Pulsed X-Rays, Oscillating Magnetic Fields (OMF). Processing technique used for the particular products should be optimized. The selection of particular preservation method for the particular food product is based on the following criteria like cost of production, scale of production, type of product either milk, meat, poultry, fruits or vegetables, shelf life and end product usage either ready-to-eat or ready-to-cook product. The non thermal techniques are recently used for all the food products for shelf life extension.

This paper deals with different non thermal methods of processing the food, its working mechanism and its application in various food processing industries. The advantages and disadvantages are also reviewed for its suitability in different food industries.

II. MICROWAVE HEATING

Microwave heating refers to the use of electromagnetic waves of certain frequencies to generate heat in material. When a microwavable container with food is placed in a microwave oven and then a oven is activated, the food at the edge of the container heats faster and a temperature gradient develops between the centre and the edges. For food applications most commonly used microwave frequencies are 2450MHz and 915MHz.

Meat, fish, fruit, butter and other foodstuffs can be tempered for cold store temperature to around -3ºC for ease of further processing such as grinding the meat in the production of burgers or blending and portioning butter packs. Food products, such as bread, precooked foods and animal feedstuffs have been processed using microwaves for pasteurisation or sterilisation or simply to improve their digestibility. The sterilisation of bone meal and the processing of barley to achieve starch to gelatine conversion [18].A 915-MHz Microwave-Circulated Water Combination (MCWC) heating technology was validated for a macaroni and cheese product using inoculated pack studies. Trays of macaroni and cheese products were subjected to 3 processing levels: target process (F0 = 2.4), under target process (F0 = 1.2), and over target process (F0 = 4.8). The inoculated packs were evaluated by count-reduction method and end-point method. MCWC heating technology has potential in sterilizing packaged foods [10].

2.1 Mechanism

2.1.1 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 [13] [19] [2]

2.1.2 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 collided with other molecules to produce heat [13] [19][2].Microwave oven generally consists of the following basic components [13][2]

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. Frequency of 2450 MHz has been set aside for microwave oven for home use

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

Stirrer: it is commonly used to distribute microwaves from the waveguide and allow more uniform heating of food

Turntable: it rotates the food products through the fixed hot and cold spots inside the cooking cavity and allows the food products 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: it allows the access of food to the cooking cavity. The door and choke are specially engineered that they prevent microwaves from leaking through the gap between the door and the cooking cavity.

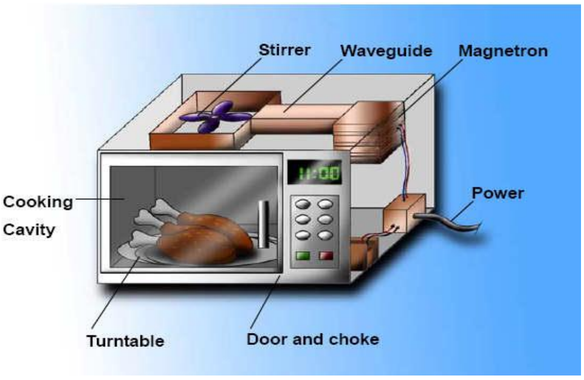

Fig 1 Basic structure of a microwave oven

2.2 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 may reach temperature above 100 ^{o}C during microwave cooking. Paper and board can also absorb some microwave energy. However, it is not ideal for microwaved food because the strength of the paper would be affected when wet and not all types of paper are suitable for microwave cooking. When food is microwaved, heat is also retained in the glass. The degree of energy absorption depends on the types of glass. Moreover, microwave energy can be superimposed at the centre after passing through the glass containers, particularly the ones with small radius.

2.2 Applications of Microwave Heating

Microwave is used in baking, concentration, cooking, curing, drying, finish drying, freeze drying, pasteurising, sterilizing, tempering and thawing

III. PULSED ELECTRIC FIELD (PEF) TECHNOLOGY

PEF is a non-thermal food preservation technology that involves the discharge of high voltage electric pulses (up to 70 kV/cm) into the food product, which is placed between two electrodes for a few microseconds [1]. It is the emerging technologies for the replacement of traditional thermal pasteurization among non-thermal processes, apart from microfiltration eventually combined with moderate heat treatment [12][21][24]. An external electric field is used to exceed a critical transmembrane potential of one volt. This result in a rapid electric breakdown and conformational changes of cell membranes, which leads to the release of intracellular liquid, and cell death [11].However, treatment temperature should be kept as low as possible in order to avoid heat damage to the treated 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 a-helix in papain secondary structure [31]. In orange juice PEF treatment at 35kV/cm for 59□s was good when compared with those of heat pasteurization at 94.6^{o}C for 30 seconds [30]. PEF treatment of ham shows changes in tissue structure leading to weight increase after brine injection and greater water holding capacity and less loss during cooking. PEF treatment causes porous, swamp- like structure which holds injected brine better then untreated ham. The PEF treated ham was significantly softer and tender then untreated samples [28].

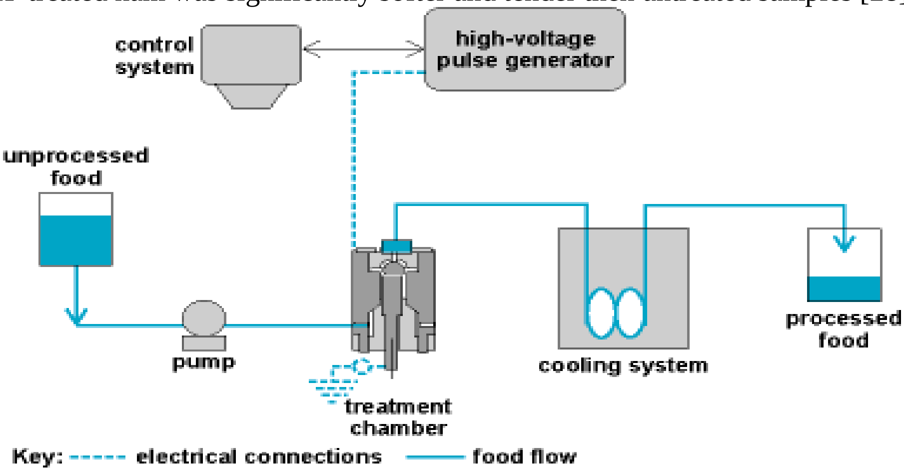

Fig 2 PEF Set-up

The typical components of PEF processing equipment include

A 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).

An energy storage element: either electric (capacitive) or magnetic (inductive).

A switch which may be either closing or opening. Devices suitable for use as the discharge switch include a mercury ignitron spark gap, a gas spark gap, a thyratron, a series of SCRs, a magnetic switch or a mechanical rotary switch
A pulse shaping and triggering circuit in some cases.
A treatment chamber: a wide variety of designs have been developed by individual laboratories).
A pump to supply a feed of product to the chamber.
A cooling system to control the temperature of the feed and/or output material.

3.1 Mechanisms of Microbial Inactivation

3.1.1 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 cell. The increase in the membrane potential leads to reduction in the cell membrane thickness.

3.1.2 Electroporation

Electroporation 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 after being exposed to an electric field, and permeation then causes swelling and eventual rupture of the cell membrane. The main effect of an electric field on a microorganism cell is to increase membrane permeability due to membrane compression and poration.

3.2 Applications of PEF Technology

PEF is used in processing of apple juice, orange juice, processing of milk, liquid whole eggs, baking applications and processing of green pea soup.

3.2 Advantages of Pulsed Electric Fields

It kills vegetative cells .Colours, flavours and nutrients are preserved. There is no evidence of toxicity and also short treatment time. Gentle preservation of liquid foods at ambient or slightly elevated temperature

IV. HIGH PRESSURE PROCESSING (HPP)

High Pressure Processing is also known as “High Hydrostatic Pressure” or “Ultra High Pressure” processing. HPP uses up to 900MPa to kill many of the micro organisms found in foods, even at room temperature without degrading vitamins, flavor and colour molecules in the process. When high pressures up to 1000MPa 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 350MPa applied for 30min or 400MPa for 5min will cause a tenfold reduction in vegetative cells of bacteria, yeasts or moulds [14].High pressure processing has no “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 [4]

4.1 High Pressure Processing Equipment

HPP unit consists of a pressure vessel and a pressure generating device. Food packages are loaded onto the vessel and the top is closed. The pressure medium usually water is pumped into the vessel from the bottom. Once the desired pressure is reached, the pumping is stopped, valves are closed, pressure can be maintained without further need for energy input. A principle underlying HPP 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.

Main components of a high pressure system are,

- A pressure vessel and its closure
- A pressure generation system
- A temperature control device
- A materials handling system

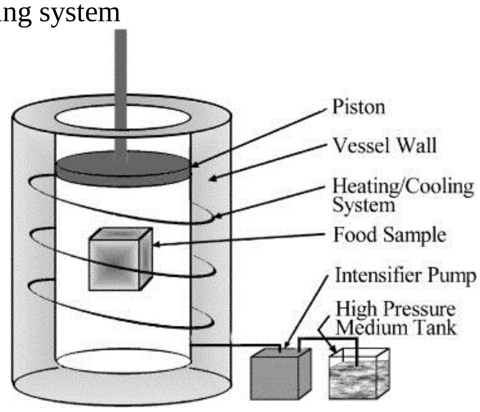

Fig 3 HPP Equipment

HPP conditions of 50 MPa at 25°C for 3 days was reported to have the potential to accelerate the ripening of Cheddar cheese. These conditions were applied to commercial Cheddar cheese.A treatment of 400 MPa at 20°C resulted in significant inhibition of micro-organisms. 3 log reduction in the case of the bacterial species and 6 log in the case of the *Penicillium* mould. The Gram positive *S. aureus* species was more resistant to pressure than the Gram negative *E. coli* species. The mould species, though at lower pressures (<300 MPa) was more resistant than the bacteria, was much more sensitive at higher pressures. Pressures of > 400 MPa were required to cause greater than 50% denaturation of whey protein [3]

There are two processing foods in high pressure vessels: in-container and bulk processing.

In-container processing

Advantages

- Applied to all solid and liquid foods
- Minimal risk of post processing contamination
- No major developments needed for HPP
- Easier cleaning

Limitations

- Complex material handling
- Little flexible in choice of container
- Greater dead time in use of pressure vessel

Bulk processing

Advantages

- Simple material handling
- Great flexible in choice of container
- Maximum efficiency in use of HP vessel volume
- Minimum vessel dead line (no opening/ closing of vessel needed)

Limitations

- Only suitable for pump able foods
- Potential post processing contaminations
- All components in contact with food must have Aseptic design.

4.2 Applications of HPP

Used in pasteurization and sterilization of fruits and fruit products, sauces, pickles, yoghurt, pasteurization of meat and vegetables, decontamination of high risk products, high value products and Sterilization of heat sensitive ingredients like shellfish, flavorings, and vitamins.

4.3 Advantages of HPP

It kills vegetative bacteria and spores; there is no evidence of toxicity, reduced processing time. Freshness, flavor, nutrients, color, and taste ate retained. Uniformity of treatment throughout the food is achieved and elimination of chemical preservatives. In pack processing is possible and low energy consumption.

V. PULSED LIGHT (OR) HIGH INTENSITY LIGHT TECHNOLOGY

High intensity light is also described as pulsed broad spectrum white light is a decontamination or sterilization technology that can be used for the rapid inactivation of micro organisms on food surfaces, equipments and food packaging materials. Surface decontamination of food products using pulsed high intensity light has many potential benefits to the food industry. It is a non thermal preservation intervention, with the ability to minimize the deleterious effects of thermal processing and chemical treatments on quality and sensory attributes.
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 one to twenty flashes per second of electromagnetic energy.
Ozer and Demirci [20] have reported a 1.09 log reduction for *Listeria monocytogenes* on raw salmon filets after 180 pulses of light and Sauer and Moraru [23] achieved a 7.15 log CFU reduction of *Escherichia coli* in apple juice. Gomez-Lopez [9] achieved a range of 0.5 – 2.04 log reduction of mesophilic, aerobic microbes naturally found in minimally processed vegetables such as spinach, iceberg lettuce, cabbage, celeriac, green bell peppers and soybean sprouts, using a treatment dose of up to 2.700 light pulses. The decontamination of bulk tank milk with pulsed UV light was investigated by Smith *et al* [26].

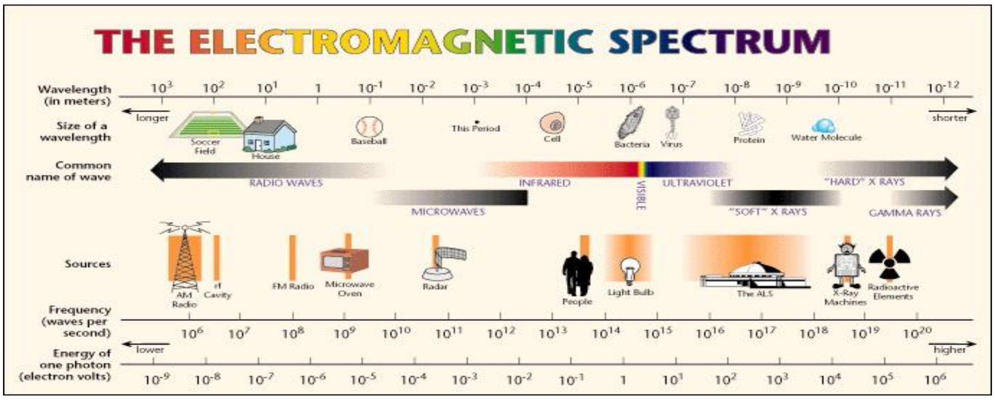

Fig 4 Electromagnetic spectrum

5.1 Process and Equipment

The principle involved in generating high intensity light is that a gradual increase of low to moderate power energy can be released in highly concentrated bursts of more powerful energy. The key component of a Pulsed Light unit is a flash lamp is filled with an inert gas, such as Xenon, which emits broadband radiation that ranges from the UV cut off of the envelope material (about 180 nm) to NIR (around 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 cause excitation of the latter, which then emit an intense, very short light pulse (1 μs to 0.1 s). The exact mechanisms by which Pulsed Light causes cell death are not yet fully understood, but it is generally accepted that UV plays 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. Some studies also indicated observable injurious effects on yeast cells and mold spores following exposure to Pulsed Light. The survival curves for the PL treatment display an obvious nonlinear decline, evidence of tailing, and a concave upward shape.

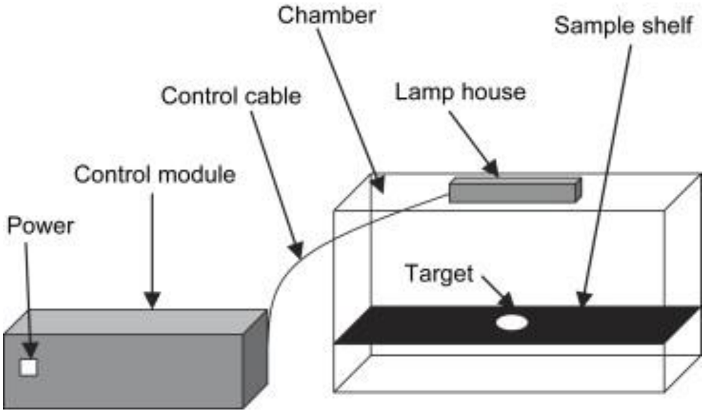

Fig 5 Pulsed Light setup

The main limitation of Pulsed Light treatment 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, nonreflecting 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 limiting the degree of microbial reduction. For any Pulsed Light treatment to be fully effective, uniform, 360° exposure of the treated food is critical. Depending on the product characteristics, limited heating effects can be noticed. Heating is usually too modest to account for microbial inactivation or to cause structural and sensory changes in the treated products.

5.2 Applications of High Intensity Light Technology

Used in decontamination of vegetables, dairy products. Also used in microbial inactivation of water, sanitation of packaging materials and disinfection of equipment surfaces.

VI. OHMIC HEATING

Ohmic heating is based on the principle of passing an electric current through an electrically conducting product, as with microwave energy, 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 products can be cooled in continuous heat exchangers and then aseptically filled into pasteurized containers in a manner similar to conventional aseptic packaging. Both high and low acid products can be processed by this method. Ohmic heating cannot be used for all the food products. It is depending upon the product’s electrical conductivity and on whether the product is an insulator or a conductor. In this process 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 electric field strength.

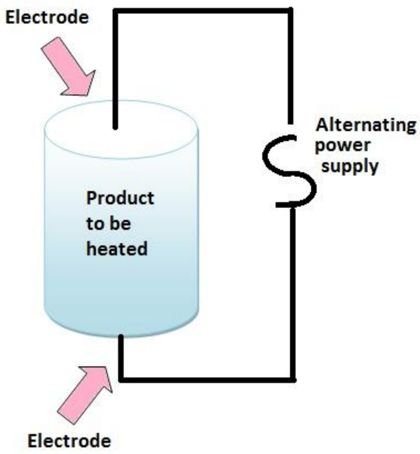

Fig 6 Ohmic heating of food

Fruits were analysed for Electrical conductivity during Ohmic heating. At 25°C the electrical conductivity of pineapple was very low and significantly different than apples and pear. Electrical conductivity of peach and strawberry was high. At higher temperatures (40-140°C), apples and pineapple had low conductivity. Strawberry and peach had higher conductivity and significantly different compared to other fruits. The gap in the electrical conductivity between strawberry and peach, and other fruits increased with the temperature [22]. Cloudberry jam was treated with ohmic heating and also by traditional method. There is no significance difference for sensory attributes and rhelogical properties between ohmic heated jam and jam prepared by another method [17].

6.1 Applications of Ohmic Heating

Used in blanching, evaporation, dehydration, fermentation, extraction and value added process

VII. ULTRASONICS

The frequency of sound waves audible to human ear ranges from 20Hz to 20 kHz. The sound waves having frequencies greater than 20 kHz are called "Ultrasonics" or "Supersonics". The term supersonics is used for sound waves having velocities greater than that of sound. Sound waves of frequencies less than 20 Hz are called "Infrasonics".
Ultrasonically enhanced drying was carried out at lower temperatures than the conventional methodology which reduces the probability of oxidation or degradation in the material. By employing ultrasound the heat transfer between a solid heated surface and a liquid is increased by approximately 30-60% [8]. Application of power ultrasound is benefit in ice cream manufacturing by reducing crystal size, preventing incrustation on freezing surface [32]. Inconsistency in beef tenderness has been rated as one of the major problems faced by the meat industry [16]. Tenderness is influenced by composition, structural organization and the integrity of skeletal muscle [15]. Ultrasound-assisted process of meat tumbling caused the significant improvement of the yield, tenderness and juiciness of the end product [6]. Sonication resulted in decreased drip loss and shear force of PSE meat [7],[29].

7.1 Production of Ultrasonics

7.1.1 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.

7.1.2 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.

7.1.3 Magnetostriction Generator

According to this effect 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 a rapidly varying magnetic field 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 is ranges from 8000Hz to 20,000Hz.

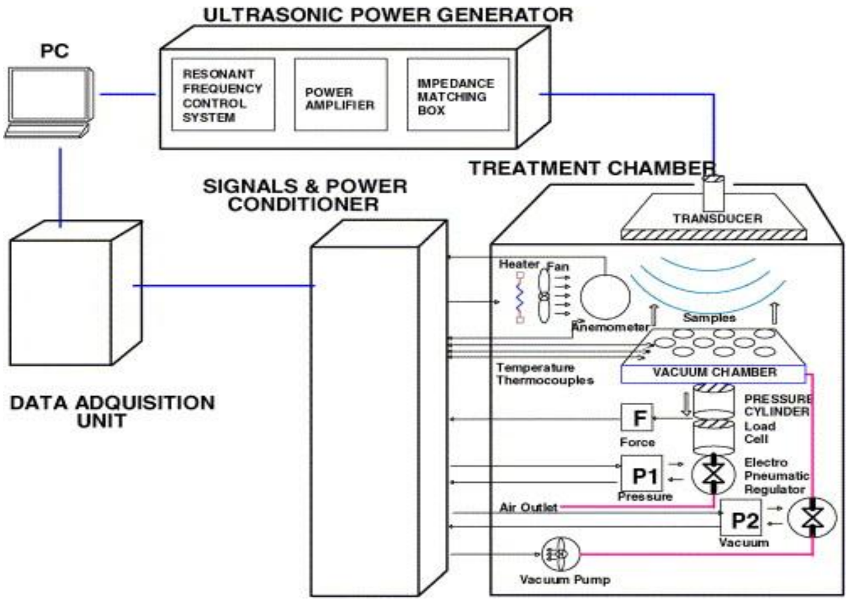

Fig 7 Ultrasonics in Food

7.2 Applications of Ultrasonics

Used in pasteurization at mild heat**,** extraction, enzyme inactivation**,** emulsification**,** crystallisation, viscosity alteration and degassing**,** spraying or coating, anti fouling and de-foaming

VIII. 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 (60-400cm) depending upon the energy used.

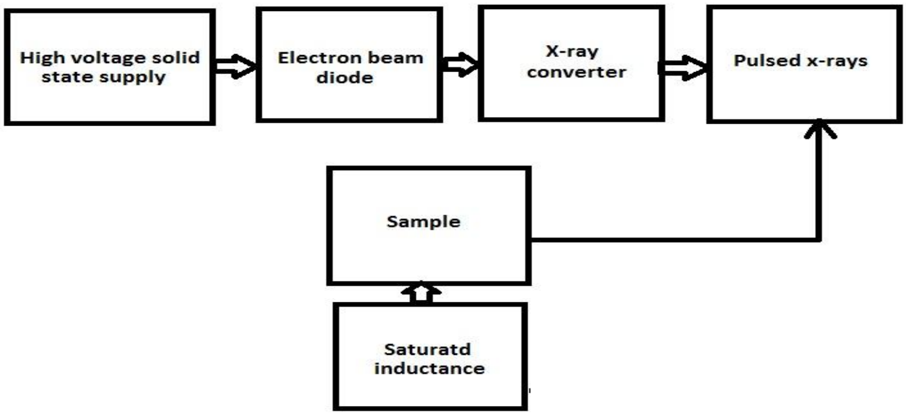

Fig 8 Pulsed X-ray setup

Curry and others [5] used a system consists 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 convertor. 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 sequentially steps up the voltage pulse before it is used to charge an inductive load. Energy from capacitor is transferred from the inductive load in approximately 100ns. A convertor is installed on the accelerator and the electron beam is converted to pulsed x-rays to allow thick samples to be processed. Curry and others [5] used pulsed x-rays to produce up to a 3 log reduction of e-coli O157:H7 in ground beef.

8.1 Applications of Pulsed X-Rays

Use in examination of packaged food for tramp materials, inactivation of e-coli in meat also used to eliminate Salmonella from foods.

IX. Results and Discussion

The review made on new trends in food processing like microwave heating, Pulsed Electric Field (PEF) Technology, High Pressure Processing (HPP), Pulsed Light Technology, Ohmic Heating, Ultrasonics and Pulsed X-Rays on the basis of principle operation, advantages and disadvantages and applications. It was found that this new trend in food processing was suitable for liquid foods than solid and semi-solid and also for processing of ready-to-cook packed foods. A trial version is proposed to process bio-beverages. It is also reviewed that uniform distribution of heat is not achieved in processing of solid foods using new trends in food processing. Investment cost of new methods of food processing is quite high and it can be applied to large scale industries when compared to small scale industries. The better quality is achieved in non thermal processing and its shelf life is also increased by this method.

X. Future Work

A proposal is made to process a bio-beverage is made by adding required quantity of carrot juice to milk with some amount of sugar and a bit of cardamom. This bio-beverage is standardized by heating it to 15psi in normal pressure cooker. Since this bio-beverage is rich in carotene due to the presence of carrot juice, it can be retained by processing through Pulsed Electric Field technology. Since this technology has very simple design and principle when compared to other technology employed in the other new trends.

XI. Conclusion

The main problem with the thermal processing of food is loss of volatile compounds, nutrients, and flavour. To overcome these problems non thermal methods came into food industries to increase the production rate and profit. The non thermal processing is used for all foods for its better quality, acceptance, and for its shelf life. The new processing techniques are mostly employed to the liquid packed foods when compared to solid foods. Since the non thermal methods are used for bulk quantities of foods, these methods of food preservation are mainly used in the large scale production. The cost of equipments used in the non thermal processing is high when compared to equipments used in thermal processing. After minimising the investment costs of non thermal processing methods, it can also be employed in small scale industries.

REFERENCES

[1]. Angersbach, A., Heinz, V. & Knorr, D. (2000) "Effects of pulsed electric fields on cell membranes in real food systems", Innovative Food Science & Emerging Technologies, Vol 1(2), pp 135-149.

[2]. Buffler, CR (1993),"Microwave cooking and processing", Engineering fundamentals for the food scientist. New York: Van Nostrand Reinhold

[3]. Beresford, T.P., O.Reilly, C., O.Connor, P., Murphy, P.M. and Kelly, A. (1998)."Acceleration of cheese ripening: current technologies, potential use of high pressure". Proceedings of VTT Symposium 186, 103 - 114. Helsinki, Finland.

[4]. Cano.M.P.,Hernandez.A and De Ancos.B.(1997),"High pressure and temperature effects on enzyme inactivation in strawberry and orange products", J.Food Sci. Vol 62, pp85

[5]. Curry.R, Unklesbay.N, Clevenger.T, Brazos.B, Mesyats.G and Filatov.A (1999),"The effect of high doses rate x-rays on e-coli O157:H7 in ground beef", IEEE on Plasma Science.in print.

[6]. Dolatowski Z.J., Stasiak D.M.,(1995)."Tumbling machine with ultrasound". In: The 9th Congress of Food Science and Technology. Budapest, 153.

[7]. Dolatowski Z.J., Stasiak D.M., Giemza S.,(2001). "Effects of sonication on properties of reduced pH meat". Pol. J. Food Nutr. Sci. 10/51, 3(S), pp192-196

[8]. Ensminger D., (1988). "Acoustic and electro acoustic methods of dewatering and drying". Drying Techn. 6, 3, pp473-499.

[9]. Gómez-López V.M., Devlieghere F., Bonduelle V. & Debevere J. (2005). "Intense light pulses decontamination of minimally processed vegetables and their shelf-life". International Journal of Food Microbiology, 103 (1), pp 79-89.

[10]. Guan.D, Gray.P, Kang.D.H, Tang.J, Shafer.B, Ito.K, Younce.F and T.C.S. Yang. "Microbial validation of Microwave Circulated Water Combination heating Technology by inoculated pack studies ". Journal of Food Science. Vol 68, pp1428-1432.

[11]. Hamilton, W. A. & Sale, A. J. H. (1967)"Effects of high electric fields on microorganisms: Ii. Mechanism of action of the lethal effect",Biochimica et Biophysica Acta (BBA) - General Subjects, 148(3), pp 789-800.

[12]. Heinz V., Alvarez I., Angersbach A., Knorr D,(2002) "Preservation of liquid foods by high intensity pulsed electric fields – basic concepts for process design", Trends Food Sci. Technol. Vol 12, pp103–111.

[13]. Hill, A and ILSI (1998), Europe Microwave Oven Task Force. Microwave Ovens. Brussels: ILSI Europe;

[14]. Hoover.D.G., Merick.C., Papineau.A.M., Farkas.D.F., and Knorr.D (1989),"Application of high hydrostatic pressure on foods to inactivate pathogenic and spoilage organisms for extension of shelf life", Food Technology Vol 43(3), pp 99.

[15]. Jayasooriya S.D., Bhandari B.R., Torley P., D'Arcy B.R., (2004). "Effect of high power ultrasound waves on properties of meat: a review". Int. J. Food Prop. 7, 2, pp301-319.

[16]. Koohmaraie M., (1996). "Biochemical factors regulating the toughening and tenderization processes of meat". Meat Sci. 43 (Supplement 1), S193-S201.

[17]. Lindbom Ingela *et al* (2006). "Ohmic heating in a food application-quality evaluation of cloudberry jam".33rd International conference of SSCHE,Tatranske Matliare, Slovakia. May 22-26, 2006. ISBN 80-227-2409-2

[18]. Metaxas, A. C. and Meredith, R. J.: Industrial microwave heating (IEE, 1983, reprinted 1988 and 1993)

[19]. Ohlsson, T. (1993),"Domestic use of microwave ovens.",Encyclopaedia of food science food technology and nutrition". Vol. 2, pp. 1232-1237.

[20]. Ozer N.P. & Demirci A. (2006). "Inactivation of Escherichia coli O157:H7 and *Listeria monocytogenes* inoculated on raw salmon filets by pulsed UV-light treatment". International Journal of Food Science and Technology, 41, pp354-360.

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

[22]. Sanjay S.Sarang (2007).”Ohmic heating for thermal processing of low acid foods containing solid particulates”. Dissertation work in Ph.D, Ohio State University.
[23]. Sauer A., & Moraru C.I. (2009). “Inactivation of Escherichia coli ATCC 25922 and *Escherichia coli* O157:H7 in apple juice and apple cider, using pulsed light treatment”. Journal of Food Protection, 72, 937-944.
[24]. Sensoy I., Zhang Q.H., Sastry S.K.,(1997),”Inactivation kinetic of *Salmonella dublin* by pulsed electric fields, J. Food Proc. Eng. Vol 20,pp 367–381
[25]. Singh, RP and Heldman, DR (1993) “Introduction to Food Engineering” San Diego: Academic Press, Inc.
[26]. Smith.W.L.,Lagunas-solar.M.C. and Cullor.J.S (2002) “Use of pulsed ultraviolet laser light for the cold pasteurization of bovine milk”, J.Food Protec Vol 65, pp1480-1482
[27]. Klonowski *et al* (2006).“Applications of pulsed electric field technology for the food”.
[28]. Toepfl, S., Ruehle, C., Heinz, V. and Knorr, D. (2005) “PEF Fish and Meat Processing”. Presented at: Workshop of IFT Nonthermal Processing Division,September 14 – 16th, Philadelphia. US
[29]. Twarda J., Dolatowski Z.J., (2006). “The effect of sonication on the colour and WHC of normal and PSE pork”. Anim. Sci. 1, Suppl., pp184-185.
[30]. 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(10): pp 4597-4605.
[31]. Yeom HW, Zhang QH and Dunne CP. (1999). “Inactivation of papain by pulsed electric fields in a continuous system”. Food Chemistry.Vol 64: pp 53-59
[32]. Zheng L., Sun D.-W., (2006). “Innovative applications of power ultrasound during food freezing processes – a review”. Trends Food Sci. Techn. 17, pp16-23.

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