International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 3, pp: 374-388 www.ijaem.net ISSN: 2395-5252

Review on Newer Techniques in Food Processing and Nanotechnology

Anjali Gautam1*, Devina Vaidya[2], Manisha Kaushal[3], Anil Gupta[4], Chetna Sharma[1], Kanchan Bhatt[1], Pooja Soni[1] and Priyanka Arya[1]

[1]PhD Student, Dr Yashwant Singh Parmar University of Horticulture & Forestry Nauni, Solan, HP
[2]Principal Scientist, Dr Yashwant Singh Parmar University of Horticulture & Forestry Nauni, Solan, HP
[3]Scientist, Dr Yashwant Singh Parmar University of Horticulture & Forestry Nauni, Solan, HP
[4]Technical Assistant, Dr Yashwant Singh Parmar University of Horticulture & Forestry Nauni, Solan, HP
Corresponding author- Anjali Gautam* (anjaligautam1409@gmail.com)

Date of Submission: 25-07-2020 Date of Acceptance: 05-08-2020

ABSTRACT: Nanotechnology is helping to considerably improve, even revolutionize, many technology and industry sectors: information technology, energy, environmental science, medicine, homeland security, food safety, and transportation, among many others. Today's nanotechnology harnesses current progress in chemistry, physics, materials science, and biotechnology to create novel materials that have unique properties because their structures are determined on the nanometer scale. This paper summarizes the various applications of nanotechnology in recent decades.

Keywords: Ohemic heating, Inductive heating, Pulsed X- Rays And Nanotechnology

I. OHEMIC HEATING

INTRODUCTION

Heating is an important step in food processing. Heat treatment has always been the most common method in the food industry for the conservation, cooking and enzymatic inactivation of raw biomaterials. Heat treatment for complex food fluids is considerably improved when newer systems such as microwave heating, inductive or ohmic (or direct electrical) heating are used. These heating methods generate heat inside the food and depend less on thermal conduction and convection and so cause fewer temperature gradients. Ohmic technology is considered a major advance in the continuous processing of particulate food products. Ohmic heating of food products involves the passage of alternating electrical current through them, thus generating internal heat as the result of electrical resistance. Most food heating processes would not normally rank highly in any listing of green processes since the amount of energy needed to raise a food through a given temperature range is the same no matter what process is employed. Ohmic heating also known as moderate electric fields heating has drawn much attention in the food processing industries. This technique has proven to be mild processing technology which preserves nutritional, functional, structural, and sensory properties of food products better than conventional heating technologies (Knirschet al., 2010; Vorobiev and Lebovka, 2009).

PRINCIPLE

The electrical circuit: Voltage, current and resistance are the primary characteristics of any electrical circuit. Voltage is the electrical driving force and can be supplied from a variety of sources such as the ac mains supply, battery, or a generator. This driving force causes a flow of electric current measured in amperes and the physical makeup of the circuit (wires, etc) contribute a resistance that opposes the flow and is measured in ohms. In ohmic heating, this resistance is provided by the food material through which the current is passed. To provide a physical or visual analogy to this abstract process, the concept of water flowing from a tap and garden hose is often used. For electrical systems, this relationship is known as Ohm’s Law and is given as

$V=I\ X R$

Where, V is the voltage (volts), I is the amperage (amperes) and R is the resistance (ohms (Ω)). It is also interesting to note that in conventional heating of food a similar law exists where the driving force for heat transfer to the food (temperature difference) equals the product of the flow rate of thermal energy multiplied by the resistance to heat flow.

MECHANISM OF OHMIC HEATING

A material to be ohmically heated, it must be physically capable of conducting electricity. For a material to be classified as a conductor, electrical charges must be able to move from one point to another within it to complete an electrical circuit. While we are well used to the concept of metals being the best conductors of electricity (wires, etc.) and display metallic conduction due to the relatively free movement of electrons through metallic lattices, even solid foods are vastly different from metals. However, most foods contain high levels of water and dissolved salts and these solutions can conduct electricity through electrolytic conduction.

Factors Influencing Heat Generation Rate

The rate of heat generation during ohmic heating is influenced by both the electrical field strength E and the electrical conductivity k.

Electrical field strength

The main method of adjusting the electrical field strength is to change the applied voltage. Additionally, it can be varied by adjusting the gap between the electrodes.

Electrical conductivity

Basic physics dictates that the electrical conductivity of a product determines its suitability for ohmic heating.4 While it has been stated that it is theoretically possible to provide any food with enough ohmic power to induce a target temperature rise, this could require using increasingly large current densities or increasingly large electrical field strengths for foods where the electrical conductivity values become very large or very small respectively. However, practical limits to electrical field strength and current density will be dictated by safety, cost and product quality considerations. Pietteet al. (2001) have also reported that ohmic heating is only practically possible between a range of electrical conductivity values (0.01 S m-1 to 10 Sm-1) and that it works optimally in the range of 0.1 to 5 S m-1.voltage. Additionally, it can be varied by adjusting the gap between the electrodes.

Temperature vs. electrical conductivity

Parrot6 states that in general, the electrical conductivity of food products increases with temperature and it is believed that this increase is mainly due to increased ionic mobility. This agrees with the work of Shirsatet al. (2004) who showed that the conductivity of model and commercial meat batters increased with temperature across a range 15-80 °C. A similar effect of temperature on electrical conductivity was also found by Pietteet al. (2004). This phenomenon is often factored into the design of continuous ohmic heaters for pumpable fluid foods.

II. PHYSICAL AND CHEMICAL CHANGES TO FOODS DURING OHMIC HEATING

Nutritional Effects

The limited literature on the nutritional impact of ohmic heating has been reviewed by Ruanet al. (2002). These workers categorized ohmic heating effects on nutrient losses into thermal destruction and diffusion but also mention the possibility of electrolysis at the electrodes which leads to product contamination. In relation to thermal destruction, Lima et al. (1999) found no significant difference when they compared the impact of electrical vs. conventional heating on ascorbic acid (vitamin C) degradation in orange juice.

Protein coagulation/denaturation

In the area of protein coagulation/denaturation under ohmic heating, much of the work has been in the area of surimi production. Wastewater from this process can contain relatively high levels of protein which contribute to a high biological oxygen demand (BOD) of the water which requires long treatment time and large storage capacity when treated by traditional methods. Kanjanapongkulet al. (2009) described the construction of a laboratory scale ohmic heating system, which was capable of heating the waste water to a sufficient temperature (60- 70 °C) to coagulate the protein (which could then be removed by centrifugation) thus reducing the BOD of the wastewater.

Advantages and Disadvantages of Ohmic Heating

Advantages	**Disadvantages**
➢ The target temperature achieved very quickly. ➢ High energy conversion efficiencies at low maintenance costs. ➢ The instant shutdown of the system ➢ No residual heat transfers after current shut down. ➢ Reduced maintenance costs	➢ Narrow frequency band. ➢ Coupling between temperature and electrical file distribution is very complicated. ➢ Lack of generalized information. ➢ Request adjustment based on the conductivity of the food material. ➢ Difficult to monitor and control

because of the lack of moving parts ➢ Reduced problems of surface fouling ➢ A quiet environmentally friendly technology.	

III. APPLICATIONS OF OHMIC HEATING

Ohmic heating has enormous potential for use in the food industry. Food ohmic heat is used for microbial inactivation, pasteurization, extraction, blanching, thawing, starch gelatinization, and evaporation. This method can be applied to various food products. However, some food products should be prepared for ionic content improvement and solid-phase conductivity [Goullieux and Pain, 2014].

Microbial Inactivation

The inactivation of the microorganisms has significant impacts on the temperature and electrical current. A 1% increase in the temperature can decrease over 9% of the population of the first microorganisms, and a 1% rise in the current of the electricity used can decrease over 20% of the Zygosaccharomycesrouxii population in orange juice [Hashemiet al., 2019]. The inactivation of Alicyclobacillusacidoterrestris spores using ohmic heating also proved to be more effective than the conventional heating of orange juice.

The applied thermal treatment for microbial inactivation in foods reduced if there is any injury due to electric current [Sastry and Palaniappan]. In ohmic heating microorganisms are inactivated thermally but due to the presence of the electric field it may occur non-thermal cellular damage in the food [Cho et al., 1999, Pereira et al., 2007 and Sun et al., 2008].

Drying

Ohmically heated samples dried at faster rate than raw samples for most treatment combinations in vacuum dryer. The maximum reduction of drying time by using ohmically pre-heated sample was 24%. Ohmic treatment helps in a significant decrease in time required for vacuum drying and which positively effects the economic and product quality [Zhong and Lima, 2003]. The applied ohmic heating can beneficially change the mass transference with accelerated rate [Moreno et al., 2012].

Blanching and Enzyme Inactivation

One of the advantages of ohmic blanching is that it able to maintain high solids content during blanching while conventional blanching use the excessive amounts of water (60 kg/400 L). The weight loss during ohmic blanching in the range did not affected by frequency and waveform. Ohmic blanching is popular due to its volumetric heating rates, rapid process, and the enhancement of mass transfer even at relatively low temperatures [Sensoy and Sastry, 2004].

IV. APPLICATIONS IN FOOD PRODUCTS

A large number of applications exist for ohmic heating including fruits and vegetables, milk product, meat product etc. Some of these applications are discussed as below:

Fruits and vegetables

The concentration of vitamin C in conventionally heated juice is lower than continuous ohmic heated juice [Lee et al., 2012]. Papaya pulp after ohmic heating retains 86.44% lycopene, 87.13% β-carotene and 85.23% ascorbic acid [Gomathyet al., 2015]. Based on the applied voltage gradient there is slight change in the pH of the tomato samples. The pH after ohmictreatments of the tomato samples was in the range of 4.20–4.51. The pH decreases with increased the voltage gradient. However, there are no differences in pH among all ohmic heated ready to eat pineapple samples at different voltage gradient. Different indirect ohmic heating conditions did not affect pH of the ready to eat fruits [Darvishiet al., 2012].

TSS content of the samples treated with 20 V/cm at 60°C and 40V/cm at 60°C of packing solution temperature had the lowest change as compared to the other treatments. Heat treatment often damages the cellular structure of fruits and accelerates loss of TSS from the fruit. Minimum use of heat was preferred for ready to eat fruit product. Changes in textural firmness of ready to eat pineapple subjected to various indirect ohmic heating treatments then stored at 4°C.

Meat and poultry products

Ohmic heating could be a fast-alternative method for meat cooking (Saranget al. 2008) and thawing (Icier et al. 2011). Ohmic cooking offers the potential for safer meat products by effectively inhibiting microbial growth through uniform temperature distribution in the product and cooking instantly inside the food (Mitelutet al. 2011). Turkey meat was cooked using ohmic heating, yielding high quality products with an 8-15-fold reduction in cooking time (Zell et al. 2010). The quality of the ohmically heated chicken breast samples was similar or superior to that of the retort-heated samples on the basis of the measurement of water content and glutamic acid in the treated sample. The sample quality did not deteriorate or degrade during storage [Ito et al., 2014].

Seafood

Ohmic heating enhances the effectiveness of the cooking of seafood like shrimps (Robertset al. 2002), surimi (Shiba and Numakura 1992) etc. Ohmic cooking is faster and more uniform giving similar color, texture and yield compared to conventional cooking (Lascorzet al. 2016). Yongsawatdigulet al. (1995) investigated the feasibility of ohmic heating to maximize the gel functionality of Pacific whiting surimi. The ohmically heated gel showed more than a two-fold shear stress and shear strain over the gel heated in water bath.

Milk products

Ohmic heating technology was first proposed by Anderson & Finkelstein (1919) for milk heating. Plenty of investigations have proved ohmic heating to be superior method for pasteurization of milk which can minimize the fouling problem (Stancl and Zitny 2010). Ohmic heating has not only a thermal lethal effect, but also a non-thermal-lethal effect on microorganisms (Sun et al. 2008). The microbial counts from conventional heating were significantly higher than those from ohmic heating. Salmonella were completely killed by treatment of ohmic heating. The texture of ohmic and conventional heated paneer shows significant difference. The ohmically heated paneer exhibited less hardness as compare to conventionally heated paneer. For pasteurization of buffalo milk ohmic heating can be proposed as an effective technique [Kumar et al., 2014]. There was no difference in degree of protein denaturation during the ohmic heating and conventional heating [Sun et al., 2007].

Rice Bran

The percent free fatty acid (FFA) in ohmically heated bran after 75 days of storage was observed to be 4.77% whereas in case of raw bran it was 41.84%. Ohmic heating effectively checked the development of FFA in rice bran. After 75 days of storage of ohmically heated samples the acid value is 9.34% and peroxide value is 4.7 meq/kg [Dhingra and Chopra, 2014].

Thawing

The process of thawing with ohmic heating is more efficient. The heat generated throughout the material is faster and more uniform. This affects the time needed to prevent significant freezing [Liu et al., 2017]. Increasing the frequency of frozen thawing will increase the heating rate. The higher beef fat content results in lower electrical conductivity and longer cycle times [Liu et al., 2017]. Ohmic heating also decreased weight loss and frozen beef thawing period [Duygu and Ümit, 2015].

Pasteurization and Sterilization

Leizerson and Shimoni (2005) reported that ohmic heated orange juice contains higher concentrations of flavor compounds and has two times longer sensory shelf life than conventionally pasteurized juice. Elzubieret al. (2009) used ohmic heating for sterilization of guava juice. Castro et al. (2004) studied on degradation of vitamin C in strawberry products pasteurized by ohmic and conventional heating. They concluded that the presence of electric field did not affect the ascorbic acid degradation. Jun et al. (2007) developed a reusable pouch with electrodes for long term space missions.

V. INDUCTION HEATING

Introduction

Induction heating is a non-contacting and complex process that combines electromagnetic, heat transfer, and metallurgical phenomena (Rapoport and Pleshivtseva, 2007). It has several advantages in temperature uniformity, high safety, maximum production rate, flexibility and compactness of heating system, quality assurance, process repeatability, automation capability, environmental friendless, reliability, energy efficiency, and cost competitiveness. It could be possible to achieve accurate and consistent heating using induction heating because it is possible to heat specific area on metal elements. Induction heating can be explained by Faraday theory stating that a change in the magnetic environment across a conductor results in an electrical current that can be induced in that conductor (Manuel and Khan, 2016).The heating of material by means of an electric current that is caused to flow through the material or its container by electromagnetic conduction.

History

The first industrial applications of the IH phenomenon were identified in 1887 by Sebastian Z. de Ferranti, who proposed IH for melting metals, filling the first patent on industrial applications of IH. Later, in 1891, F.A. Kjellin presented the first fully functional induction furnace. The first major advance came when Edwin F. Northrup implemented the first high-frequency induction furnace at Princeton in 1916. Nearly at the same time, M.G. Ribaud developed highfrequency IH technology using spark-gap generators and, later, Valentin P. Vologdin developed IH generators using machine generators and vacuum tubes.

Principle

Induction heating system is composed of an induction coil, power supply, converters, and quenching system. The material to be heated, usually conductive and ferrous material, is placed in a fluctuating magnetic field. In metal processing, the material to be heated is called workpiece that is the product. In food processing and cooking, food material as a product is indirectly heated by conduction through a ferrous material. The electromagnetic field generates Foucault (eddy) currents in the workpiece/heatpiece, which induce Joule heating (Davies, 1997). Figure 1 shows the main components of an induction heating system.

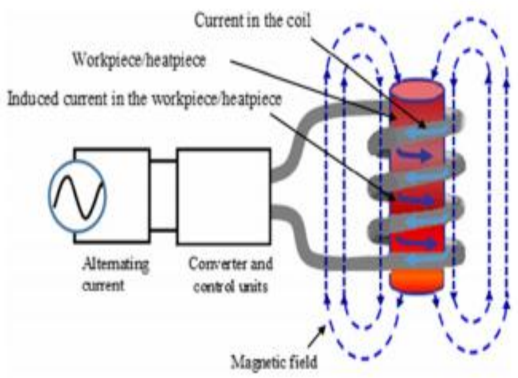


Fig 1: Main components of the induction heating system

The hysteresis effect does not occur at temperatures at temperature above the Curie point that is the temperature at which a material loses its magnetic properties. Curie temperature depends on material type and its purity. Curie temperature for nickel ranges between 353 and 360 °C (Legendre and Sghaier, 2011) and for iron is 770 °C.

Depending on the flow mode of the workpiece inside the heating coils, induction mass heating could be carried out in different heating modes: static, progressive multistage, and continuous and oscillation heating. Usually, induction coils are cooled either with air or water to keep the coils at low temperatures, and therefore, a low resistance for current flow could be attained.

Heat Transfer in Induction Heating and Material Selection for Heatpieces

Induction heating works only with conductive and ferrous materials. Depending on the material magnetic permeability and ferromagnetic properties, various metallic materials, such as steel, cast iron, among others, could be heated by induction. To heat a non-ferrous material (e.g., food materials), a ferrous material should be used as a heatpiece. During heating, the heatpiece is heated by the induced current. Then, the heat is transferred to the processed food material via heat convection between the internal surface of heatpiece and the food material and heat conduction between different layers of the food material. For a non-ferrous container (e.g., glass, copper, aluminum, and non-magnetic alloys of stainless steel), an interface sheet made of ferrous metal is used as a heatpiece.

Factors Affecting the Performance of Induction Heating Systems

There are several factors affecting the efficiency and the economics of induction heating, such as frequency and intensity of induced current; physical characteristics, dimensions, and shape of workpiece/heatpiece; design configurations of inductor; and desirable temperature range (Rudnevetal., 2003) The heating time, proper selection of power source, and control system for induction heating depend strongly on resistance and reactance of charges. The magnetic permeability of materials is strongly related to material type and composition, temperature, and intensity of magnetic field. For non-magnetic materials like copper or aluminum, the relative magnetic permeability is unity. Heat builds up quickly in high-resistance materials, such as steel, tin, and tungsten. Electrical resistivity increases with temperature; therefore hot workpieces have high accessibility for induction heating than cold pieces (Rudnevet al., 2003).

VI. APPLICATIONS OF INDUCTION HEATING IN FOOD PROCESSING

Food is a non-ferrous material and hence cannot be heated directly through induction heating, i.e. it is not possible to induce the current directly in the food material and obtain heating. Instead, a ferrous material is used as a vessel in which the food is placed. Induction heating could be a good alternative to the conventional heating technologies in food industry due to its advantages. Using induction heating for cooking flat products on a belt conveyor could save 50% of energy demand.

Induction heating is a desirable heating source for evaporation processes for organic and inorganic liquids and could replace electrical furnaces with an energy saving of 20%. Induction evaporation has several features that make it more attractive than conventional heating (Kuzmichev and Tsybulsky, 2011) It provides vapor ionization and high-density vapor plasma generation that help in obtaining high-quality coatings; it is used for evaporating chemically active, radioactive, and toxic substances and in vacuum and gas medium for the production of compound coatings and macroparticle and nanoparticle. The induction heating can be operated at high temperatures, up to 2000 °C, depending on the maximum operational temperature of evaporator materials.

Induction heating was also applied for the extraction of pectin from citrangealbedos (Zouambiaet al., 2014). Extraction experiments were carried out using an induction plate, and samples were put in magnetizable and enameled containers. The time required for the extracting process was significantly shorter using induction heating (30 min) than conventional heating (90 min).

Advantages

- Short heating cycles and high production rates
- Better metallurgical results due to fast and clean heating
- Energy savings due to selectivity and high efficiency
- Good control and repeatability
- Minimal or no surface oxidation and decarburization
- Favorable for industrial environment (no pollution)

Disadvantages

- A high frequency power source is required, which is costly and complex. Thus, initial cost required is more
- Only certain steels can be induction hardened
- The method is restricted to components having a shape that is suitable for induction hardening.
- The running cost or cost of operation is high

VII.PULSED X RAYS IN FOOD PROCESSING AND PRESERVATION

Introduction

First recognized in 1895, X-ray irradiation soon became a breakthrough diagnostic tool for the dental and medical professions. However, the food industry remained slow to adopt X-ray irradiation as a means for controlling insects and microbial contaminants in food, instead using gamma and electron beam (E-beam) irradiation. However, the reinvention of X-ray machines with increased efficiency, combined with recent developments in legislation and engineering, is now allowing X-ray to actively compete with gamma irradiation and E-beam as a microbial reduction strategy for foods.

The amount of energy deposited in a unit mass (J kg^{-1}) is measured using a standard unit called a gray (Gy), which is named in honor of the British physicist Louis Harold Gray, the father of modern-day radiobiology. Typical ionizing radiation doses for treating food products range from 1 to 44 kGy. The dose required to reduce a microbial population by 90% (i.e., 1 log) is termed the D_{10} value (kGy) (**Molins 2001**).

History of X rays

Ionizing irradiation—including gamma ray, E-beam, and X-ray—has long been recognized as a viable cold pasteurization strategy for reducing the levels of both pathogenic and spoilage microorganisms in a wide range of foods for the purpose of enhancing food safety and product shelf life. The introduction of X-rays as a source of ionizing irradiation dates back to the late nineteenth century, when German physicist W. C. Roentgen first observed the generation of radiation during his experiments with Hittorf-Crookes tubes, also known as modified cathode ray tubes.

X rays as a form of Ionizing Radiation

X-rays, or Roentgen rays, appear next to gamma rays in the electromagnetic spectrum at frequencies of 10^{16} to 10^{19} Hz. The somewhat lower energy photons emitted by X-rays are formed from the interaction of a charged particle with matter, either from replacing displaced electrons from a low-lying orbit or through bremsstrahlung, also known as braking radiation (**Newton 1963**). Machine sources of X-rays primarily use bremsstrahlung, where active photons emitted when high-velocity electrons strike a dense metal target, such as tungsten, tantalum, or gold, are directed toward the desired object. These high-energy particles alone may also generate a lower level of ionization, the technology of which has been used in the development of high-energy E-beams.

Mechanism

When an atom is exposed to X-rays, energy transactions occur between the projected photons and the orbiting electrons. These interactions result in a net transfer of energy from X-rays to electrons in the absorbing material, raising the electron excitation level (**Newton 1963**). Excitation, resulting from a low level of energy, moves an electron further out in its atomic orbit, thereby increasing the net energy. Ionization then occurs when the energy level sufficiently increases to produce highly reactive positive and negative ions by the removal of an orbiting electron (**Wilkinson & Gould 1998**).

Dose Measurement

Radiation doses are measured using ionizing radiation-sensitive materials that can be classified according to their accuracy and range. Based on accuracy of the measurement, the following four categories are now recognized: (a) primary standards (~1% to 2% uncertainty) maintained by national standards laboratories, (b) reference standards (~3% uncertainty) for calibrating radiation environments and routine dosimeters, (c) transfer standards for establishing traceability of an irradiation facility, and (d) routine standards (~5% to 10% uncertainty) for radiation process quality control, absorbed-dose monitoring, and mapping (**ISO/ASTM 2005**).

The need for alternative Microbial Reduction strategies

Across the globe, interest in ionizing irradiation has increased steadily since the beginning of the millennium, with the market for irradiation equipment increasing from 19 billion to over 25 billion U.S. dollars. The United States alone claims roughly one quarter of this spending (**Parker 2005**). Worldwide, various irradiation technologies are now being used in at least 55 countries to treat food products (**IAEA 2009**). Renewed interest in ionizing irradiation has developed in response to continued outbreaks traced to fresh produce, including lettuce (**Ethelberg et al. 2010**, **Irvine et al. 2009**, **Nygard et al. 2008**, **Sodha et al. 2011**), spinach (**Grant et al. 2008**, **Wendel et al. 2009**), and raw nuts (**Danyluk et al. 2007**, **Isaacs et al. 2005**, **Kirk et al. 2004**) because these products are are adversely affected by thermal processing. From 1998 to 2007, a total of 1,999 outbreaks and 35,554 illnesses were associated with consuming meat, poultry, and seafood, with 684 outbreaks and 26,735 cases of illness from produce (**CSPI 2009**).

Microbial reduction strategies for fresh fruits and vegetables have remained largely ineffective because of current growing/harvest/processing practices and the nature of the material.

Advances In X-Ray Technology

Reinvention of X-ray machines with increased efficiency, combined with recent developments in legislation and engineering, is now allowing X-ray to actively compete with gamma irradiation and E-beam as a microbial reduction strategy for foods. In the generation of bremsstrahlung, one of the unfortunate outcomes is the inadequate conversion of energy from integrated photons to integrated electrons, which decreases process efficiency. This has been viewed by some as the primary limitation to X-ray use for commercial applications, but is also an area of debate. Initially, the approved maximum energy level permitted for X-rays was set at 5.0 MeV; however, at an October 16–18, 1995 meeting of the FAO/IAEC/WHO in Vienna, Austria, it was concluded that X-ray machines producing up to 7.5 MeV "can be used without any concern about induced radioactivity but would be a satisfactory, efficient and cost effective addition to other radiation sources available for food processing" (**ICGFI 1995**).

VIII. HURDLE APPROACH FOR PATHOGEN CONTROL

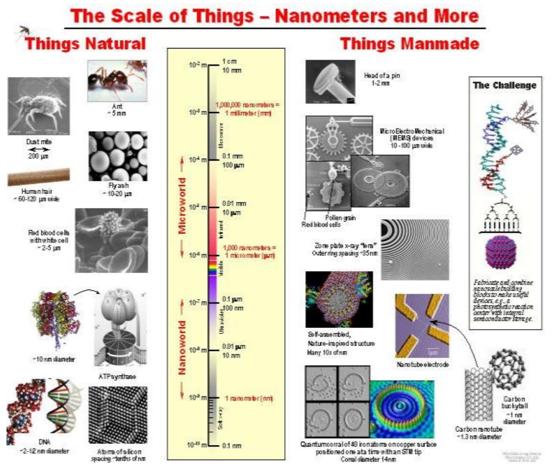
Combining irradiation with other treatments, including chemical preservatives and growth inhibitors in a hurdle approach, has been proposed as an additional option for enhancing product safety and quality. **Thayer et al. (2006)** found that irradiation and chlorination acted synergistically in the inactivation of Salmonella, E. coli O157:H7, and L. monocytogenes on fresh produce. In a separate report, **Foley et al. (2004)** determined that although water, chlorine (200 ppm), and irradiation (1.05 kGy) significantly reduced levels of E. coli O157:H7 on cilantro, combined use of irradiation with a wash treatment was superior to irradiation alone.

IX. NANOTECHNOLOGY

WHAT IS NANO- The word "Nano" is a Greek word meaning "dwarf"-A nanometer is 1/1,000,000,000 (1 billionth) of a meter, which is around 1/75,000 of the diameter of a human hair or the space occupied by 10 Hydrogen atoms lined end to end- 1 nm. 1 Nanometer = 10-9 meter.

DEFINITION: Nanotechnology is the creation of functional materials, devices and systems, through the understanding and control of matter at dimensions in the nanometer scale length (1-100 nm), where new functionalities and properties of matter are observed and harnessed for a broad range of applications.

In other words it is 'The art and science of manipulating and rearranging individual atoms and molecules to create useful materials, devices, and systems.'



HISTORY OF NANOTECHNOLOGY:

2000 Years Ago – Sulfide nanocrystals used by Greeks and Romans to dye hair

1000 Years Ago (Middle Ages) – Gold nanoparticles of different sizes used to produce different colors in stained glass windows

1960 – "There is plenty of room at the bottom" by R. Feynman

1974 – "Nanotechnology" - Taniguchi uses the term nanotechnology for the first time

1981 – IBM develops Scanning Tunneling Microscope

1985 – "Buckyball" - Scientists at Rice University and University of Sussex discover C60

1986 – "Engines of Creation" - First book on nanotechnology by K. Eric Drexler. Atomic Force Microscope invented by Binnig, Quate and Gerbe

1989 – IBM logo made with individual atoms

1991 – Carbon nanotube discovered by S. Iijima

1999 – "Nanomedicine" – 1st nanomedicine book by R. Freitas

2000 – "National Nanotechnology Initiative" launched

2001- "U.S announces first centre for military application

NANOBIOTECHNOLOGY: is the convergence of engineering and molecular biology that is leading to new class of multifunctional devices and system for biology and chemical analysis with better sensitivity and specificity.

This research field includes two main approaches:

- ✓ Application of nano-scaled tools to biological system.
- ✓ Use of biological systems as template in the development of novel nano–scaled products.

TYPES OF NANOPARTICLES:

THIN FILM: Single "two dimensional" film, thickness < ~100 nm.Electrons can be confined in one dimension; affects wave function, density of states.Boundaries, interfaces affect transport.

Applications:

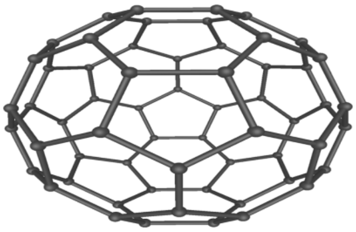
- Solid Fuel Cells
- Thin Film Transistors for liquid crystal displays
- Gas sensing applications
- Thin layers in electronic devices

FULLERENES:

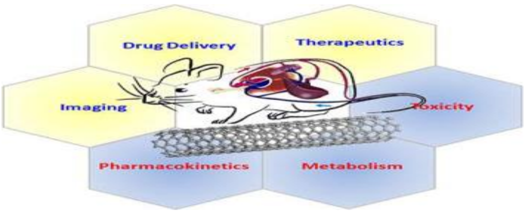
- A fullerene is any molecule composed entirely of carbon in the form of a hollow sphere, ellipsoid or tube.
- Spherical fullerenes are also called buckyballs and they resemble the balls used in football.
- Cylindrical ones are called as carbon nanotubes or buckytubes.
- Fullerenes are similar in structure to graphite.
- The first fullerene molecule to be discovered was buckminsterfullerene (C60) prepared in 1985

APPLICATIONS OF FULLERENES:

- Antiviral activity
- Antioxidant activity
- Fullerenes in drug and gene delivery
- Diagnostic application etc.



CARBON NANOTUBES:



NANORODS:

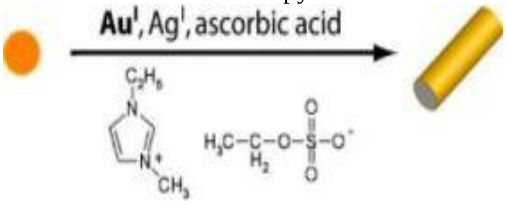
In Nanotechnology nanorods are one morphology of nanoscale objects

- ❖ Each of their dimensions range from 1-100nm
- ❖ They may be synthesized from metals or semiconducting materials

❖ Nanorods are produced by direct chemical synthesis

APPLICATIONS:

- ✓ Nanorods generate heat when excited with IR light. This property has led to the use of nanorods as cancer therapeutics. Nanorods can be conjugated with tumor targeting motifs.
- ✓ Golden Nanorods are also used for Medical Applications: **tumor treatment**
- ✓ **Bock Staller**and his team have synthesized gold nanorods using an ionic liquid as a solvent. Gold nanorods are interesting starting materials in cancer therapy.



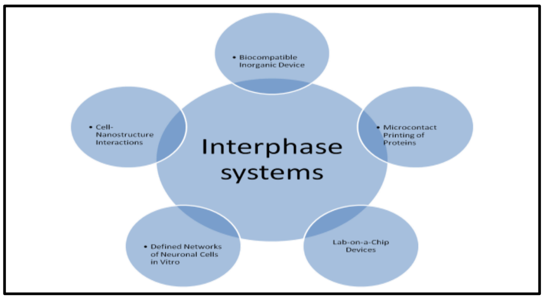
NANOFLUIDS: Nanofluid is a fluid containing nanometer sized particles, called nanoparticles.The nanofluids used are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oilExample: Nanofluidic diodes

APPLICATIONS

- ▪ Analytical separations and determinations of biomolecules, such as proteins and DNA
- ▪ Nanofluidics had a significant impact in biotechnology, medicine and clinical diagnostics with the development of lab-on-a-chip devices for PCR and related techniques

Dendrimers: are repetitively branched molecules. The name comes from the Greek word δένδρον (Dendron), which translates to "tree". The first dendrimers were made by divergent synthesis approaches by Fritz Vogtle in 1978

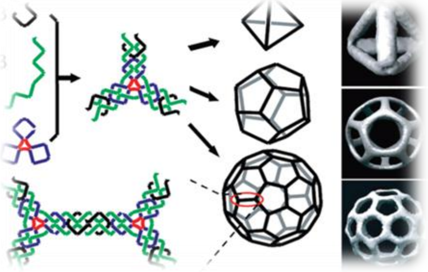
- ● **INTERPHASE SYSTEM:** Progress in medical device technology is clearly linked to progress in materials science technology, and new materials which have been developed for very different applications have influenced the design and also the mechanical, chemical, and biological properties of implants.
- ● Nanotechnology can, in certain very well-defined areas, improve the biocompatibility of implants either passively by the use of thin films, or actively by releasing therapeutic agents from implant surfaces.

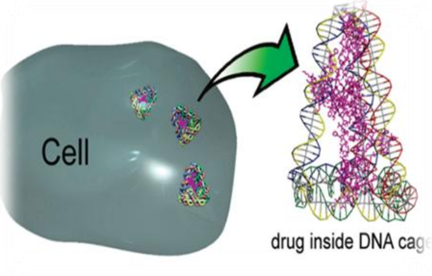


DNA NANOTECHNOLOGY:

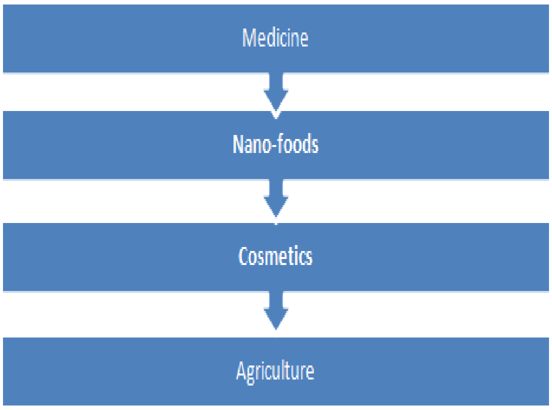
DNA is an excellent nanoconstruction material because of its inherent merits:

- ✓ The rigorous Watson-Crick base pairing makes the hybridization between DNA strands highly predictable.
- ✓ The structure of the B-form DNA double helix is well-understood.
- ✓ DNA possesses combined structural stiffness and flexibility. The rigid DNA double helices can be linked by relatively flexible single-stranded DNA (ssDNA) to build stable motifs with desired geometry.





APPLICATIONS OF NANOTECHNOLOGY:



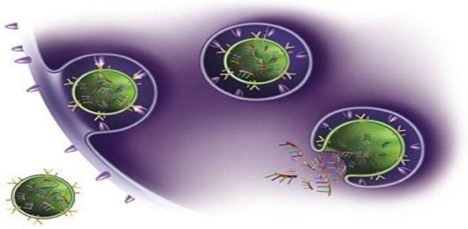
MEDICINE: Nanometer-sized particles have optical, magnetic, chemical and structural properties that set them apart from bulk solids, with potential applications in medicine

Potential applications

- ❖ DRUG DELIVERY
- ❖ MEDICAL IMAGING
- ❖ DIAGNOSIS & SENSING
- ❖ THERAPY

DRUG DELIVERY: A nanoparticle carries the pharmaceutical agent inside its core, while its shell is functionalized with a 'binding' agent

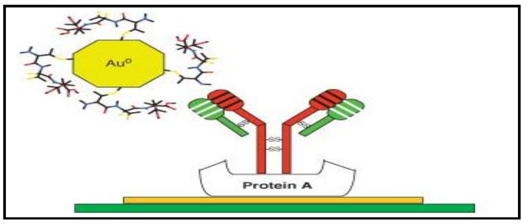
1) Through the 'binding' agent, the 'targeted' nanoparticle recognizes the target cell. The functionalized nanoparticle shell interacts with the cell membrane
2) The nanoparticle is ingested inside the cell, and interacts with the biomolecules inside the cell
3) The nanoparticle particles breaks, and the pharmaceutical agent is released



MEDICAL IMAGING: Optical properties of nanoparticles depend greatly on its structure. Particularly, the color (wavelength) emitted by a quantum dot (a semiconductor nanoparticle) depends on its diameter.

DIAGNOSIS AND SENSING:

- ✓ Diseases can be diagnosed through the (simultaneous) detection of a (set of) biomolecule(s) characteristic to a specific disease type and stage (biomarkers).
- ✓ Each cell type has unique molecular signatures that differentiate healthy and sick tissues. Similarly, an infection can be diagnosed by detecting the distinctive molecular signature of the infecting agent
- ✓ A nanoparticle can be functionalized in such a way that specifically targets a biomarker. Thus, the detection of the nanoparticle is linked to the detection of the biomarker, and to the diagnosis of a disease



THERAPY: Nanometer-sized particles are particularly responsive to electromagnetic and acoustic excitations through a variety of phenomena (e.g. plasmon resonance) that lead to local extreme conditions (e.g. heating). The nanoparticle is able to tolerate this condition, but no so the biological material nearby.

Cancer nanotechnology:

- ✓ Cancer nanotechnology: Cancer nanotechnology, as a particular area of nanomedicine, is based upon the same premise that nanoparticles display unique properties potentially useful in medical (oncological) applications.
- ✓ Nanoparticles in the size range of 5-100nm have enough surface area to be properly functionalized to bind specific targets, with a variety of ulterior purposes.

Nano-medicines: With Nanomedicine, we will be able to think of today's incurable diseases as curable tomorrow, by looking at a problem at its molecular and atomic levels. But nanomedicine is not developing today as fast as other technologies.

Nanofood:

- ✓ The potential benefits of Nanofoods – foods produced using nanotechnology – are astonishing.

- ✓ Promise improved food processing, packaging and safety, enhanced flavour and nutrition where everyday foods carry medicines and supplements.
- ✓ The ongoing debate over nanofood safety and regulations has slowed the introduction of nanofood products:
- ✓ Examples :
- ✓ Canola active oil, Nanotea
- ✓ Nanoceuticals Slim Shake

COSMETICS:

- ✓ One field of application is in sunscreens, anti-aging creams, toothpastes, hair care and perfumes.
- ✓ The traditional chemical UV protection approach suffers from its poor long-term stability.
- ✓ A sunscreen based on mineral nanoparticles such as titanium dioxide, gold palladium offer several advantages.

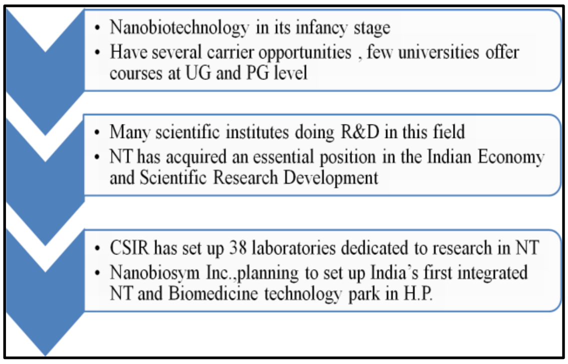
AGRICULTURE:

- ✓ Crop improvement
- ✓ Analysis of gene expression and Regulation
- ✓ Soil management
- ✓ Plant disease diagnostics
- ✓ Efficient pesticides and fertilizers
- ✓ Water management
- ✓ Monitoring the identity and quality of agricultural produce

FEW NANOTECHNOLOGY COMPANIES IN INDIA:

S.No.	COMPANY	MANUFACTURING PRODUCTS
1.	Auto Fiber Craft (AFC)	Nano-size Silver Powder for use in electronic applications
2.	Bee Chems	Various grades of Nano Silica products
3.	DaburPharma	Polymeric nanoparticles for drug delivery
4.	Mp3s Nanotechnolog	Equipment for textile waste water recycling
5.	Macromaterias (India)	Material catalysts
6.	NanoBio Chemicals	High quality nanoparticles
7.	United Nanotechnologies	Nanoparticles based coating

NANOBIOTECHNOLOGY STATUS IN INDIA :



- Nanobiotechnology in its infancy stage
- Have several carrier opportunities , few universities offer courses at UG and PG level

- Many scientific institutes doing R&D in this field
- NT has acquired an essential position in the Indian Economy and Scientific Research Development

- CSIR has set up 38 laboratories dedicated to research in NT
- Nanobiosym Inc.,planning to set up India's first integrated NT and Biomedicine technology park in H.P.

X. CONCLUSION:

There is much debate on the future implications of nanotechnology in biological systems. It could create and suggest implementation of a choice of various new materials and devices potentially useful in the field of medicine, electronics, biomaterials and energy production.Nevertheless, this approach raises many of the same issues as any new technology, including problems with toxicity and environmental impact of nanomaterials and their potential effects on global economics, as well as speculation about various doomsday scenarios. Scientists and researchers should work on reducing the potential risks associated with the technology proper regulatory authorities and regulatory acts should be framed & enforced so as to increase popularity and acceptance of technology among common people.

REFERENCES:

[1]. Agostinelli S, Allison J, Amako K, Apostolakis J, Araujo H, et al. 2003. G4—a simulation toolkit.Nucl.Instrum. Methods Phys. Res. Sect. A Accel., Spectrom., Detect. Assoc. Equip. 506:250–303
[2]. Allali H, Marchal L and Vorobiev E. 2009.Drying Technology: An International Journal. 27(6):739-746.
[3]. Amine A, Mohammadi H, Bourais I and Palleschi G (2006). Enzyme inhibition based biosensors for food safety and environmental monitoring. Biosensors and Bioelectronics 21: 1405-1423

[4]. Anderson AK, Finkelsten R. 1919. A Study of the Electro-pure process of treating milk.J Dairy Sci. 2: 374-406.

[5]. Arvanitoyannis IS, Stratakos A, Mente E. 2009a. Impact of irradiation on fish and seafood shelf life: a comprehensive review of applications and irradiation detection. Crit. Rev. Food Sci. Nutr. 49:68–112

[6]. Arvanitoyannis IS, Stratakos AC, Tsarouhas P. 2009b. Irradiation applications in vegetables and fruits: a review. Crit. Rev. Food Sci. Nutr. 49:427–462

[7]. Atyhanov A and Sagyndikova A. 2013.Energy savings at the induction method of grain drying.Applied Technologies & Innovations. 9:17-20.

[8]. Aworh OC, Okparanta RN, Oyedokun EO. 2002. Effect of irradiation on quality, shelf life and consumer acceptance of traditional Nigerian meat and fish products. In Study of the Impact of Food Irradiation on Preventing Losses: Experience in Africa, IAEA-TEC-DOC-1291, pp. 39–45 Vienna, Austria: Int. At. Energy Agency

[9]. Ay MR, Zaidi H. 2005. Development and validation of MCNP4C-base Monte Carlo simulator for fan- and cone-beam X-ray CT. Phys. Med. Biol. 50:4863–85

[10]. Baysal AH and Icier F. 2010. “Inactivation kinetics of Alicyclobacillusacidoterrestris spores in orange juice by ohmic heating: Effects of voltage gradient and temperature on inactivation,” J. Food Prot. 73(2):299–304.

[11]. Behrens JH, Barcellos MN, Frewer LJ, Nunes TP, Landgraf M. 2009. Brazilian consumer views on food irradiation. Innov.Food Sci. Emerg. Technol. 10:383–89

[12]. Bergonie J, Tribondeau L. 1959. Interpretation of some results of radiotherapy and an attempt at determining a logical technique of treatment.Radiat. Res. 11:587–88

[13]. Borsa J, Chu R, Sun J, Linton N, Hunter C. 2002.Use of CT scans and treatment planning software for validation of the dose component of food irradiation protocols.Radiat. Phys. Chem. 63:271–75

[14]. Bozkurt H, Icier F. 2012. Ohmic thawing of frozen beef cuts. J Food Process Eng. 35: 16-36.

[15]. Brescia G, Moreira R, Braby L, Castell-Perez E. 2003.Monte Carlo simulation and dose distribution of low energy electron irradiation of an apple. J. Food Eng. 60:31

[16]. Castro I, Teixeira JA, Salengke S, Sastry SK and Vicente AA. 2004. Innovative Food Science and Emerging Technologies. 5:27-36.

[17]. Castro I, Teixeira JA, Salengke S, Sastry SK, Vicente AA. 2004. Ohmic heating of strawberry products: Electrical conductivity measurements and ascorbic acid degradation kinetics. Innov Food SciEmerg Technol. 5(1): 27-36.

[18]. Chinnamuthu C R and Kokiladevi E (2007). Weed management through nanoherbicides. In: Application of nanotechnology in agriculture. C.R. Chinnamuthu, B. Chandrasekaran, and C. Ramasamy (Eds.) Tamil Nadu Agricultural University, Coimbatore, India

[19]. Cho HY, Yousef AE and Sastry SK. 1999.Biotechnology and Bioengineer, 62(3), 368-372.

[20]. Darvishi H, Hosainpour A and Nargesi F. 2012.J Nutr Food Sci. 2:167.

[21]. Davies EJ. 1990. Conduction and induction heating. Peter Peregrinus Ltd., London.

[22]. De Alwis AAP and FryerPJ. 1990. Chemical Engineering Science4:1547-1599.

[23]. Dhingra D. and Chopra S. 2014.Agricultural Engineering Today, 38(2):1-6.

[24]. Duygu B, Umit, G. 2015. Application of ohmic heating system in meat thawing.Procedia Soc Behav Sci., 195: 2822-2828.

[25]. El-Fouly MEZ, Karem HA, El-Din NS, Farag DE, El-Khatib M, Mageed MA. 2002. Commercial feasibility and evaluation of consumer acceptance for certain irradiated food products in Egypt. In Study of the Impact of Food Irradiation on Preventing Losses: Experience in Africa, IAEA-TEC-DOC-1291, pp. 39–45. Vienna, Austria: Int. At. Energy Agency

[26]. Elzubier AS, Thomas CSY, Sergie SY, Chin NL, Ibrahim OM. 2009. The effect of buoyancy force in computational fluid dynamics simulation of a two-dimensional continuous ohmic heating process.Am J Appl Sci., 6(11): 1902-1908.

[27]. Ethelberg S, Lisby M, Bottiger B, Schultz AC, Villif A, et al. 2010. Outbreaks of gastroenteritis linked to lettuce, Denmark, January 2010. Euro.Surveill. 15:1–3 Eustice RF, Bruhn CM. 2010. Consumer acceptance and marketing of irradiated meat. In Case Studies in Novel Food Processing Technologies: Innovations in Processing, Packaging, and Predictive Modelling, ed. CJ

Doona, K Kustin, FE Feeherry, pp. 442–463. Cambridge, UK: Woodhead. 560 pp.

[28]. Foley D, Euper M, Caporaso F, Prakash A. 2004. Irradiation and chlorination effectively reduces Escherichia coli O157:H7 inoculated on cilantro (Coriandrumsativum) without negatively affecting quality. J. Food Prot. 67:2092–98

[29]. Food and Drug Administration. 2004. Irradiation in the production, processing and handling of food. Fed.Regist. 69(246):76844–47 http://edocket.access.gpo.gov/2004/pdf/04-28043.pdf

[30]. Fox JA, Hayes DJ, Shogren JF. 2002. Consumer preferences for food irradiation: how favorable and unfavorable descriptions affect preferences for irradiated pork in experimental auctions. J. Risk Uncertain. 24:75–95

[31]. Gomathy K, Balakrishnan M and Thangavel K. 2014 .Trends In Biosciences, 7(20):3301-3305

[32]. Gomathy K, Thangave K, Balakrishnan M, Kasthuri R. 2015. Effect of ohmic heating on the electrical conductivity, biochemical and rheological properties of papaya pulp.J Food Process Eng. 38(4): 405-413.

[33]. Goullieux A and Pain JP. 2014. “Chapter 22 -Ohmic Heating,” D.-W. B. T.-E. T. for F. P. (Second E. Sun, Ed. San Diego: Academic Press:399–426.

[34]. Hashemi SMB, Mahmoudi MR, Roohi R, Torres I and Saraiva JA. 2019. “Statistical modeling of the inactivation of spoilage microorganisms during ohmic heating of sour orange juice,” LWT, vol. 111: 821–828.

[35]. Hillie T and Hlophe M (2007).Nanotechnology and the challenge of clean water.Nature Nanotechnology 2: 663–664

[36]. Hong S, Leroueil P R, Majoros I J, Orr B G, Baker J R and BanaszakHoll M M (2007). The binding avidity of a nanoparticle based multivalent targeted drug delivery platform. Chemical Biology 14: 107-115

[37]. Hu Y, Shen G, Zhu H and Jiang G (2010). A class-specific enzyme linked immunosorbent assay based on magnetic particles for multiresidueorganophosphorus pesticides. Journal of Agricultural and Food Chemistry 58: 2801–2806

[38]. Icier F, Izzetoglu GT, Bozkurt H, Ober A. 2010.Effects of ohmic thawing on histological and textural properties of beef cuts.J Food Eng. 99: 360-365.

[39]. Icier F. 2010.Journal of Food Process Engineering. 33(4): 661–683.

[40]. Inmanee P, Kamonpatana P and Pirak T. 2019. “Ohmic heating effects on Listeriamonocytogenes inactivation, and chemical, physical, and sensory characteristic alterations for vacuum packaged sausage during post pasteurization,” LWT. 108:183–189

[41]. Ito R, Fukuoka M and Sato NH. 2014. Meat Science. 96(2): 675-681.

[42]. Jeong S, Marks BP, Ryser ET, Moosekian SR. 2010b. Inactivation of Escherichia coli O157:H7 on lettuce using low-energy X-ray irradiation. J. Food Prot. 73:547–51

[43]. Kanjanapongkul K, Tia S, Wongsa-Ngasri P, Yoovidhya T. 2009.Journal of Food Engineering91: 341-346.

[44]. Khodakovskaya M, Dervishi E, Mahmood M, Yang Xu, Zhongrui Li, Watanabe F and Biris A S (2009). Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. ACS Nano3: 3221–3227

[45]. Kim SS, Park SH, Kim SH, and Kang DH. 2019. “Synergistic effect of ohmic heating and UV-C irradiation for inactivation of Escherichia coli O157:H7, Salmonella Typhimurium and Listeriamonocytogenes in buffered peptone water and tomato juice,” Food Control, vol. 102:69–75.

[46]. Knirsch MC, Alves dos Santos C, Martins de Oliveira SoaresVicent AA and VessoniPenna TC. 2010. Ohmic Heating - A review. Trends in Food Science and Technology 21: 436–441.

[47]. Kumar M, Jyoti and Hausain A. 2014.Asian Journal of Dairy And Food Research. 33(1): 9-13.

[48]. Kunstadt P. 2001.Economic and technical considerations in food irradiation. In Food Irradiation: Principles and Applications, ed. R Molins, pp. 415–442. New York: John Wiley and Sons. 488 pp.

[49]. Kuzmichev A and Tsybulsky L. 2011. In: Grundas S (ed) Advances in induction and microwave heating of mineral and organic materials. In Tech publisher, Rijeka.

[50]. Lascorz D, Torella E, Lyng JG, Arroyo C. 2016. The potential of ohmic heating as an alternative to steam for heat processing shrimps.Innov Food SciEmerg Technol. 37: 329-335

[51]. Lebovka NI, Shynkaryk MV and Vorobiev E. 2006.Drying Technology: An International Journal. 24(5): 601-608.

[52]. Lee SY, Sagong HG, Ryu S, Kang DH. 2012. Journal of Applied Microbiology. 112(4):723-731.
[53]. Legendre B and Sghaier M. 2011 Curie temperature of nickel.Journal of Therm Anal Calorim. 105:141-143.
[54]. Leistritz F L, Hodur N M, Senechal D M, Stowers M D, McCalla D and Saffron C M (2007). Biorefineries using Agricultural Residue Feedstock in the Great National Academy of Agricultural Sciences 19 Plains AAE Report 07001 Working Paper, Agricultural Experiment Station, North Dakota State University, Fargo North Dakota
[55]. Leizerson S and Shimoni E. 2005.Stability and sensory shelf life of orange juice pasteurized by continuous ohmic heating.J Agr Food Chem.53(10): 4012-4018.
[56]. Lima K, Heskitt BF, Burianek LL, Nokes SE, Sastry SK. 1999.Journal of Food Processing and Preservation 23: 421-434.
[57]. Lucian SG. 2014. Optimal design approach of inductors for mass heating processes. International Journal of Application or Innovation in Engineering & Management. 3:423-427.
[58]. Manuel G and Khan M. 2016.Design of an induction heating domestic water heater system.Induction Heating Technology and Its Applications: Past Developments, Current Technology, and Future Challenges. Engineering Sciences.
[59]. Mathew AP, Laborie M P and Oksman K (2009).Cross-Linked Chitosan/Chitin Crystal Nanocomposites with Improved Permeation Selectivity and pH Stability.Biomacromolecules10: 1627
[60]. Maupin SL and Johnson LP. 2011. Anti-oxidation food preparation device, USA.
[61]. Meissner J, Abs M, Cleland MR, Herer AS, Jongen Y, et al. 2000. X-ray treatment at 5 MeV and above. Radiat. Phys. Chem. 57:647–51
[62]. Mitelut A, Popa M, Geicu M, Niculita P, Vatuiu D, Vatuiu I, Gilea B, Balint R, Cramariuc R. 2011. Ohmic treatment for microbial inhibition in meat and meat products.Rom BiotechnolLett.16(1): 149-152
[63]. Moreno J, Simpson R, Pizarro N, Parada K, Pinilla N, Reyes JE and Almonacid S. 2012. Journal of Food Engineering. 110(2):310-316.
[64]. Neetoo H and Chen H. 2014. Food Processing: Principles and Applications. In S. Clark, S. Jung and B. Lamsal (Eds.), Food Processing; Principles and Applications, John Wiley and Sons, Ltd.
[65]. Ngasri PW and Sastry SK. 2015.LWT - Food Science and Technology. 61 (2): 269-274.
[66]. Palaniappan S and Sastry S K. 1991.Journal of Food Process Engineering 14: 247-260.
[67]. Parker PM. 2005. The 2009–2014 world outlook for X-ray, beta ray, gamma ray, nuclear, and other irradiation equipment. ICON Rep. ICON Group International, Inc., San Diego, CA
[68]. Pereira R, Martins J, Mateus C, Teixeira JA and Vicente AA. 2007. Chemical Papers. 61(2):121-126.
[69]. Pham H, Jittanit W and Sajjaanantakul T. 2014.Songklanakarin Journal of Science and Technology. 36 (3): 317-324.
[70]. Piette G, Buteau ML, De Halleux D, Chiu L, Raymond Y, Ramaswamy HS and Dostie M. 2004. Journal of Food Science69: FEP71-FEP78.
[71]. Piette G, Buteau ML, Halleux D, Chiu L, Raymond Y, Ramaswamy HS and Dostie M. 2004.Journal of Food Science, 69(2): 71–78.
[72]. Piette G, Dostie M and Ramaswamy H. 2001.47th International Congress of Meat Science and Technology 62-67.
[73]. potato tissue. Bioresource Technology. 87(3): 215–220
[74]. Ranmode S. and Kulshreshtha M. 2011.Journal of Engineering Science and Technology, 6(2):228 – 239.
[75]. Rapoport E and Pleshivtseva Y. 2007. Optimal control of induction heating processes. Taylor & Francis Group, New York
[76]. Roberts JS, Balaban MO, Luzuriaga DA. 2002. Comparison of quality attributes of ohmic and water immersion thawed shrimps. J Aquat Food Prod Technol.11: 3-11.
[77]. Ruan R, Ye X, Chen P, Doona C and Taub I. 2002.Ohmic heating, In: The nutrition handbook for foodprocessors. Henry CJ K, Chapman C. Woodhead Publishing Ltd, Cambridge.
[78]. Rudnev V, Loveless D, Cook R and Black M. 2003.Handbook of induction heating.Marcel Dekker, INC., New York.
[79]. Samprovalaki K, Bakalis S and Fryer PJ. 2007. “Ohmic heating: models and measurements,” in Heat Transfer in Food Processing, vol. 13, WIT Press: 159–186.
[80]. Sarang S, Sastry SK, Knipe L. 2008.Electrical conductivity of fruit and

meat during ohmic heating.J Food Eng. 87: 351-356.

[81]. Sastry SK and Palaniappan S. 1992.Food Technology.46(12):64–67.

[82]. Sastry SK and Palaniappan S. 1992.Journal of Food Engineering.15:241-261. \

[83]. Schilling MW, Yoon Y, Tokarskyy O, Pham AJ, Williams RC, Marshall DL. 2009. Effects of ionizing irradiation and hydrostatic pressure on Escherichia coli O157:H7 inactivation, chemical composition, and sensory acceptability of ground beef patties. Meat Sci. 81:705–10

[84]. Sensoy I and Sastry SK . 2004. Journal of Food Science. 69: 7-13.

[85]. Shao L, Tian X, Yu Q, Xu L, Li X and Dai R. 2019. “Inactivation and recovery kinetics of Escherichia coli O157:H7 treated with ohmic heating in broth,” LWT. 110:1–7.

[86]. Shiba M and Numakura T. 1992.Quality of heated gel from walleyepollacksurimi by applying joule heat.Nippon Suisan Gakkaishi.58(5): 903-907.

[87]. Shirsat N, Lyng JG. Brunton NP and McKenna B. 2004.Journal of Muscle Foods15: 121-137.

[88]. Shynkaryk MV, Taehyun J, Alvarez VB and Sastr SK. 2010.Journal of Food Science. 75(7): 493–500.

[89]. Somavat R, Mohamed HMH and Sastry SK. 2013.LWT - Food Science and Technology.54(1):194-198.

[90]. Stancl J and Zitny R. 2010.Milk fouling at direct ohmic heating.J Food Eng., 99(4): 437-444.

[91]. Sun HX, Kawamura S, Himoto JI, Itoh K, Wada T and Kimura T. 2008.Food Science and Technology Research. 14:117-123.

[92]. Tomita H, Maruyama T, Yoshimura S and Takahashi N. 2009. Superheated steam generator by induction heating.13th European Conference on Power Electronics and Applications. IEEE, 2009.

[93]. Vorobiev E and Lebovka N. 2009.Electro-technologies for Extraction from Food Plants andBiomaterials. Springer Science Business Media, LLC.

[94]. Wenstrup MJ, Plans M and Rodriguez-Saona LE. 2014 Effect of a novel induction food-processing device in improving frying oil quality. International Journal of Food Science and Technology. 49:2223–2229.

[95]. Yildiz H, Icier F and Baysal T. (2010) Journal of Food Process Engineering, 33(4), 763–779.

[96]. Yongsawatdigul J, Park JW, Kolbe E, Abu Dagga Y, Morrissey MT. 1995. Ohmic heating maximizes gel functionality of Pacific whiting surimi. J Food Sci. 60: 1-5.

[97]. Zell M, Lyng JG, Cronin DA, Morgan DJ. 2010. Ohmic cooking of whole turkey meat-Effect of rapid ohmic heating on selected product parameters. Food Chem.120: 724-729.

[98]. Zhong T. and Lima M. 2003.Bioresource Technology. 87(3):215–220.

[99]. Zouambia Y, YoucefEttoumi K, Krea M and Moulai-Mostefa N. 2014. A new approach for pectin extraction: electromagnetic induction heating. Arab Journal of Chemistry.10:480-487.